EASTERN INTERCONNECTION BASELINING STUDY
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Final Report

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DISCLAIMER

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Contents

List of Figures

List of Tables

1 EXECUTIVE SUMMARY

Analysis of several major blackouts that have occurred in last twenty years worldwide have identified the need for real-time wide-area monitoring of power system dynamics using synchro-phasor system technology. With the advancement in the synchro-phasor system technology, it is now possible to identify the key system parameters such as system stress (angle differences) and other problems, such as low damped or growing inter-area oscillations or voltage degradation early enough so that the operators are alerted for taking appropriate action and avoid cascading. Programs are now available to monitor these dynamic power system metrics in real-time. However, operators need guidance in distinguishing the normal and abnormal parameter ranges that can be expected in real-time operations, as well as to define levels to alert the operators when the system is moving from a secure state to a less secure state warranting action. Some of the metrics that can be monitored in real-time using the high-speed and high-resolution synchro-phasor system data are

- Wide Area angle pairs (Inter-ISOs for wide area stress).
- Inter-area power flows and oscillations (Major inter-area power transfers).
- Voltages on sensitive/critical busses.
- Voltage and angle sensitivities at critical busses.

Electric Power Group (EPG) was asked to work with the leadership of the Operations Implementation Task Team (OITT) and the Planning Implementation Task Team (PITT) of North American Synchro-Phasor Initiative (NASPI), as well as independent system operators (ISOs), regional transmission owners (RTOs), and utilities to carry-out interconnection base-lining analysis. The PITT and OITT teams identified base-lining Eastern Interconnection phase angles as their highest priority. Although, the analysis can be conducted for all four metrics quantities, this present work has been limited mostly to "**Wide Area Angle Pair Analysis**".

The goal of this Eastern Interconnection Base-lining Analysis Project is to work with the NASPI operations and Planning teams and other CERTS research performers, such as Pacific Northwest National Laboratory (PNNL), to carry out a comprehensive base-lining analysis for establishing the high/low ranges for selected angle pairs. Since, at the time the project was launched, only the State Estimator data was available and synchro-phasor measurement system was being installed, five-minute state estimator data was used for this analysis. The study covered the four ISO regions in Eastern Interconnection, NY ISO, PJM, MISO and ISO New

England. State estimator data for period ranging from few months to about two years(2010-2011) was provided by the above ISOs and has been used in analysis. Appropriate angle pairs were selected within each region based on either input from the ISO or by analyzing different sources and sinks in the region. Detailed statistical analysis was conducted on the data extracted from the SE data and recommended range was provided for each of the angle pairs. While selecting the angle pairs, the locations were selected keeping in mind where the PMUs were being installed and angle pairs could be monitored using PMUs in future. Box-whisker plot and time duration curve were introduced to set the operational monitoring range. The methodology was applied to all four individual ISOs and Inter-ISO studies. Analysis was also conducted to investigate some points that lay outside the defined range (outliers). Investigation of some of the outliers showed that some outliers were caused by system contingencies, while in some other cases they were caused because of bad SE solution.

This preliminary work provided procedures and methods to study voltage angle data. The proposed operational monitoring ranges are based on limited state estimator data provided by four ISOs. The range should be reexamined when user wants to use values in real-time monitoring tool with at least 12-18 months history data. The monitoring range should be set based on the season and on-peak and off-peak hour type.

Since, one of the key benefit of synchro-phasor technology, is its capability to monitor wide angle pairs across ISO regions, effort was made to stitch the SE data from different ISOs and to obtain ranges for wide area (Inter-ISO) angle pairs. It was soon realized that this approach will not be feasible with SE data and synchronized phasor measurement data is required. This report presents the analysis of the four regions, investigation of some points outside the range(outliers), effort and analysis of SE data stitching and the suggested angle pairs and their range within the individual ISOs. Additional analysis for Inter-ISO angle pairs using synchr-phasor system data is in process and will be presented in the subsequent report. The results of analysis for individual ISOs have been found to be acceptable for use in monitoring. The study also analyzed the co-relation of angle differences with bus voltage at a selected bus and power flows on selected lines. A close co-relation (above 0.9) was observed between angle difference and line power flow, but co-relation of bus voltage with angle difference was observed to be relatively poor. This finding that a strong correlation exists between angle difference and power flows on specific line indicates that by monitoring the angle pairs, the operators may be able to monitor the system stress as a backup to the State Estimators. Analysis and reports have been provided to the ISO staff for use of generated information.

2 BACKGROUND

Major blackouts that have occurred in last twenty years worldwide have identified the need for real-time wide-area monitoring of power system dynamics using phasor system technology. With the advancement in the phasor system technology, it is now possible to identify the system stress and other problems, such as growing inter-area oscillations or voltage degradation early enough so that the operators are alerted for taking appropriate action and avoid cascading. Real-time Tools are available to monitor these dynamic metrics. However, operators need guidance on the normal and abnormal ranges that can be expected in real-time operations, as well as to define thresholds to alert the operators when the system is moving from a secure state to a less secure state warranting action. Some of the metrics that can be monitored using the high-speed and high-resolution phasor system data are

- Wide Area angle pairs (Inter-ISOs for wide area stress).
- Inter-area power flows and oscillations (Major inter-area power transfers).
- Voltages on sensitive/critical busses.
- Voltage and angle sensitivities at critical busses.

The Department of Energy, via Lawrence Berkeley National Lab (LBNL), commissioned Electric Power Group, LLC (EPG) to work on the Eastern Interconnection Baselining Study under subcontract 6996016. EPG is a member of the Consortium for Electric Reliability Technology Solutions (CERTS). EPG was asked to work with the leadership of NASPI's Operations Implementation Task Team (OITT) and the Planning Implementation Task Team (PITT), as well as independent system operators (ISOs), regional transmission owners (RTOs), and utilities to carry-out interconnection baselining. The PITT and OITT teams of North American SynchroPhasor Initiative (NASPI) identified baselining Eastern Interconnection phase angles as their highest priority.

The goal of this Eastern Interconnection Baselining Analysis Project is to work with the PITT and other CERTS research performers, such as Pacific Northwest National Laboratory (PNNL), to carry out a comprehensive baselining study using either 5-minute state estimator or other type of data for four Independent System Operators (ISOs) in the Eastern region. The four ISOs currently being analyzed are PJM Interconnection, Midwest ISO, New York ISO, and ISO New England. Figure 1 shows the map of the study region and Table 1 presents the peak load and generation MW for each study ISO. The data from these ISOs has been received for part of 2010 and 2011, and is in different formats covering different time frames. The Eastern Interconnection Baselining Analysis Project is made up of four (4) primary tasks and each task consists of multiple sub-tasks. There are four progress reports have been submitted. In these four progress reports, each report focuses on analysis which is based on different ISO data, identifying the major path flows, determining the suggested angle pair monitoring reference values within the ISOs, and validating information for the common angle pairs from the data received from other ISOs.

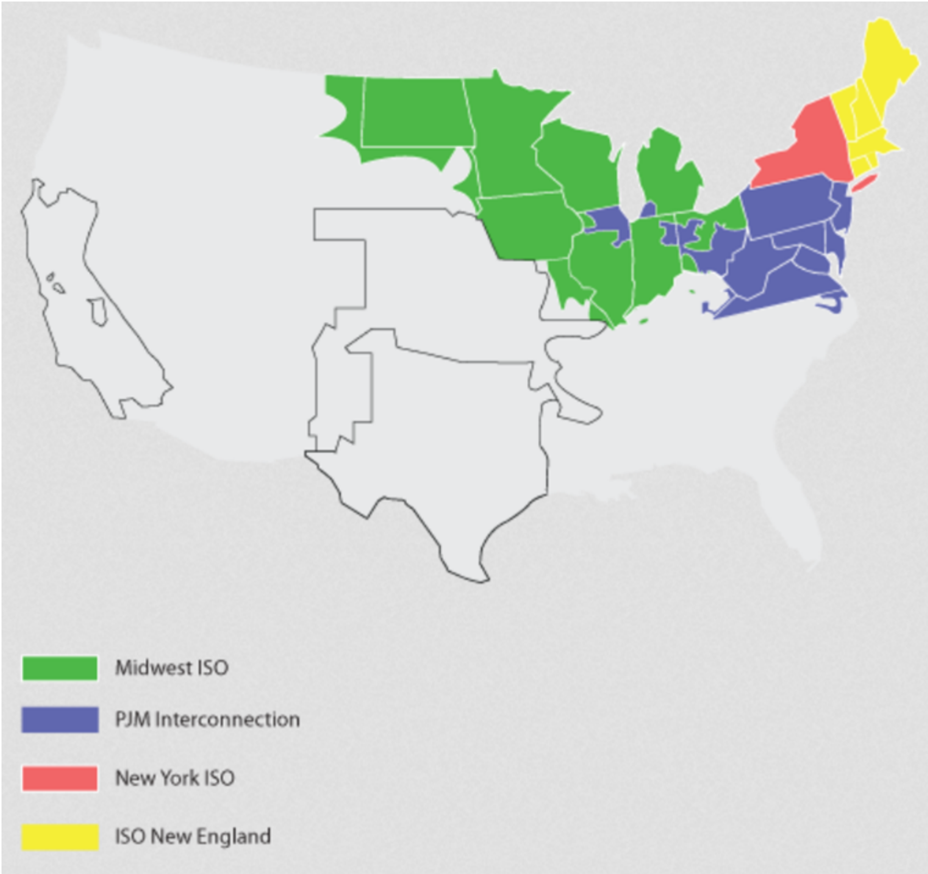


Figure 1: Study Region-Wide Area Covering Four ISOs

Table 1: Peak Load and Generation for Four ISOs

ISOs	Peak Load (MW)	Generation (MW)
NEISO	28,130	32,000
NYISO	33,865	37,707
PJM	163,848	185,600
MISO	103,975	131,010

3 DATA SOURCE

The data source for baselining study includes dataset from state estimators of PJM, MISO, NYISO and ISO-NE. The data are in different date ranges, different resolution and in different formats. PJM and MISO provide the state-estimator raw data which contains power flow, voltage angle, and voltage magnitude data for their entire control area and neighboring systems. NYISO and ISO-NE provide data in csv files which only have the bus voltage and bus angle information in their own control area.

Figure 2 shows the data time frame for four ISO data sources. PJM provides the most complete data from January 2010 to October 2011. It is found there is common date range when the data is available from all four ISOs. According to Figure2, all the ISOs have the complete data for March 2011. An analysis of wide angles across ISOs is conducted using this common date range. Figure 3 shows

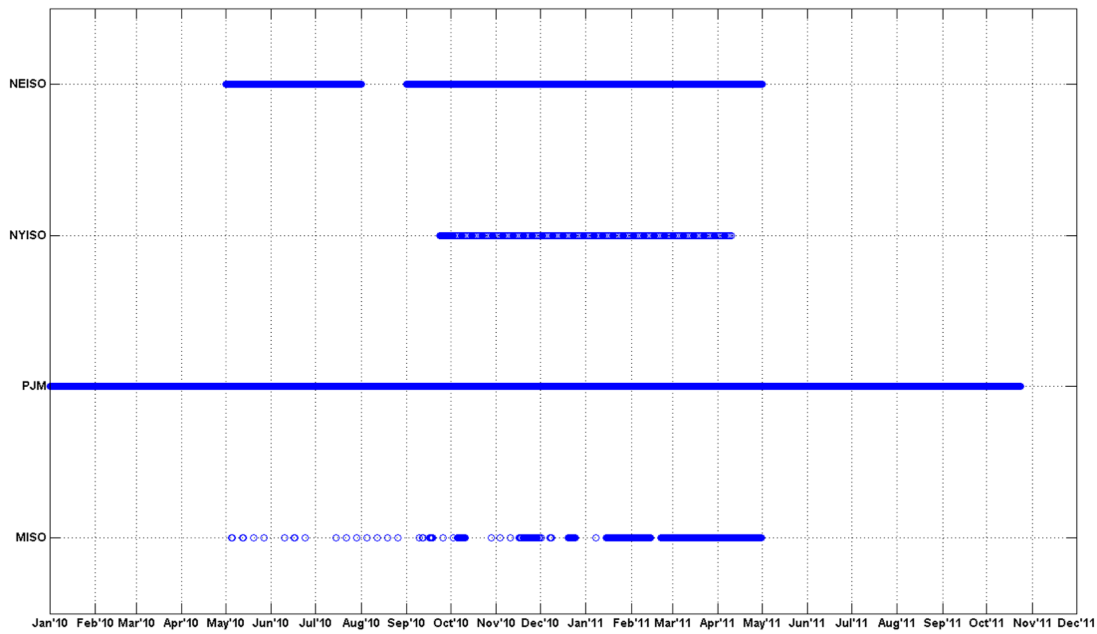


Figure 2: Time Frame of Four Data Sources (ISO-NE, NYSIO, PJM, and MISO)

the data sampling rate received from four ISOs. In this figure, 20 minutes data in March 1, 2011 from four ISOs are presented. Different ISO data show a different sampling rate. PJM and MISO provide data with 5-minute sampling rate. ISO-NE provides data with 3-minute sampling rate. NYISO data has 30-second sampling rate. Besides the different sampling rates, the time stamps from different ISOs are different which means the data is not synchronized. For the analysis across ISOs, the stitching technique has been investigated in order to bring unsynchronized data together.

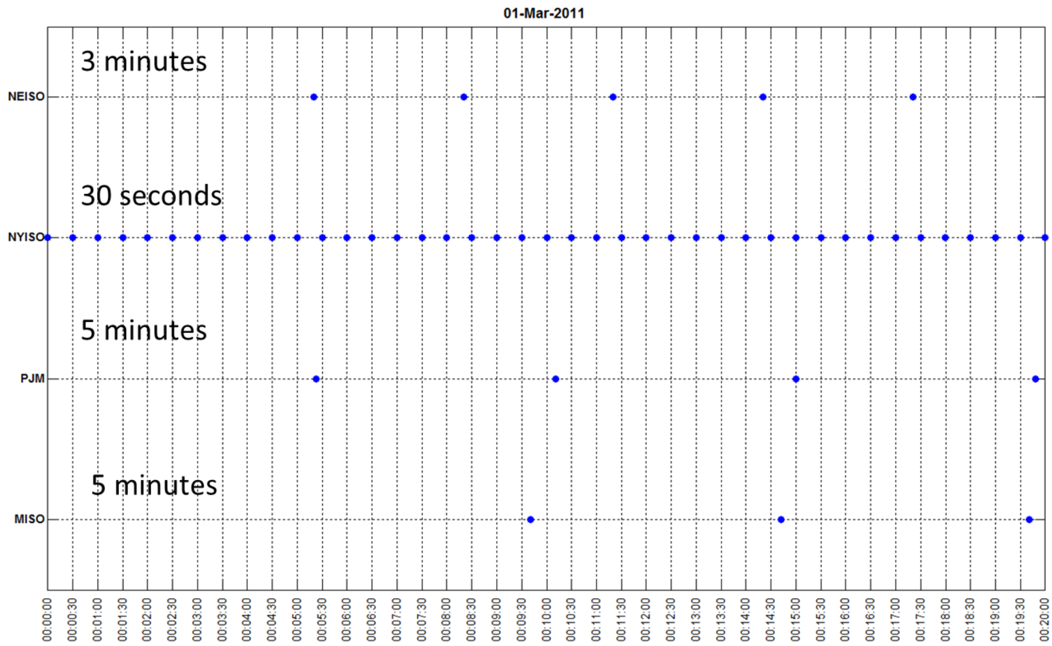


Figure 3: Data Sample Rate from Different ISOs

4 ANALYSIS APPROACH

4.1 Analysis Procedure for Each ISO

Since, the four ISOs extend over a large area, and the data are in different types of format, the analysis has been done by sorting out each data set individually. The following analysis process was followed for each ISO data analysis:

- Identify critical power paths, sources, and sinks
- Select angle pairs in each ISO
  - wide area segments within ISO
  - local or regional segments within ISO
- Extract data for selected angle pairs (wide area segments, local segments)

- Analyze past historical data (Phasor/EMS/State Estimator data) and obtain base lining high and low monitoring information for peak, off-peak, and seasonal conditions for selected angle pairs
- Identify and analyze outliers based on the established high and low monitoring values

4.2 Methodology for Establish High and Low Range Values

To establish the monitoring reference values for selected angle pairs, Box-Whiskers charts and Time Duration plots were created.

Daily phase angle is depicted as box-and-whisker plots in order to display the large amount of data in an effective way. Box-Whiskers plot is a histogram-like method of displaying data where groups of numerical data are graphically shown through their five-number summaries: the Lower Whisker, 25th percentile, median, 75th Percentile, Upper Whisker and Outlier. Data that are considered outliers have been marked with a red cross on the box plot as illustrated in Figure 4 below:

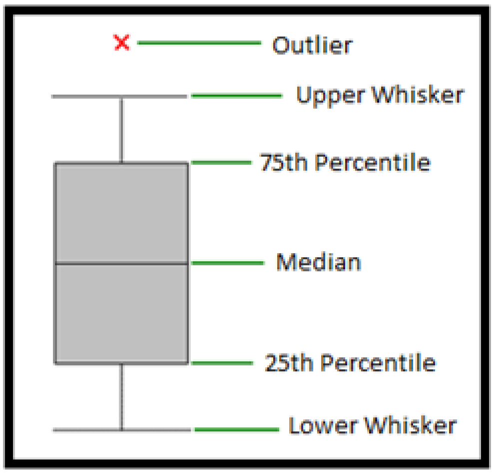


Figure 4: A Box-and-Whisker Plot

On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, and the whiskers extend to the most extreme data points not considered outliers. The outliers are drawn if they are larger than 1.5 times the difference between the percentiles from the 75th percentile (Upper Whisker) and/or smaller than 1.5 times the difference between the percentiles from the 25th percentile (Lower Whisker).

Time duration plot, similar to a Load Duration Plot, is introduced to give a visual impression of the data distribution. It is an estimate of the probability distribution of a continuous variable. It can help to identify the proportion of cases that fall into each of several categories and quickly establish the limits. From the Time Duration plot, the high and low monitoring reference values are established around to 0.5% and 99.5% of the cumulative percentage which means only 0.5% of the observations are above the high reference value and 99.5% of the observations are above the low reference value. The criteria was established based on the empirical knowledge to eliminate angle differences caused by system configuration changes like line outages or system transients. Appropriate range will help to detect the abnormal condition. But tight range to detect all events will results too many alarms and is not advisable.

Figure 5 below shows an example of Time Duration plot for establishing high and low reference monitoring values. The red lines in the figure are the high monitoring value at approximate 0.5% the cumulative percentage and low monitoring value at approximate 99.5% of the cumulative percentage. [1]

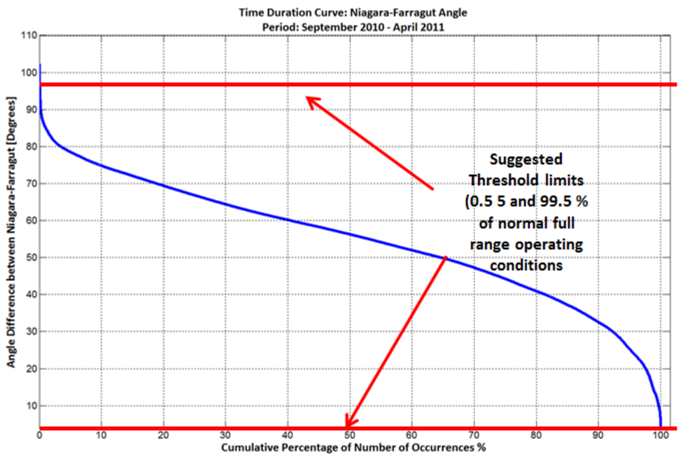


Figure 5: A Time Duration Plot

Data analysis for each ISO footprint will be described in the following sections.

[1] In this report, The terms high and low monitoring values refer to the values at 0.5% and 99.5% of time in the time duration plot unless otherwise specified.

5 DATA ANALYSIS FOR PJM FOOTPRINT[1]

5.1 Data Extraction and Analysis Procedure

Figure 6 below illustrates the flow of data as well as the process that are involved in performing the baselining analysis for the PJM area.

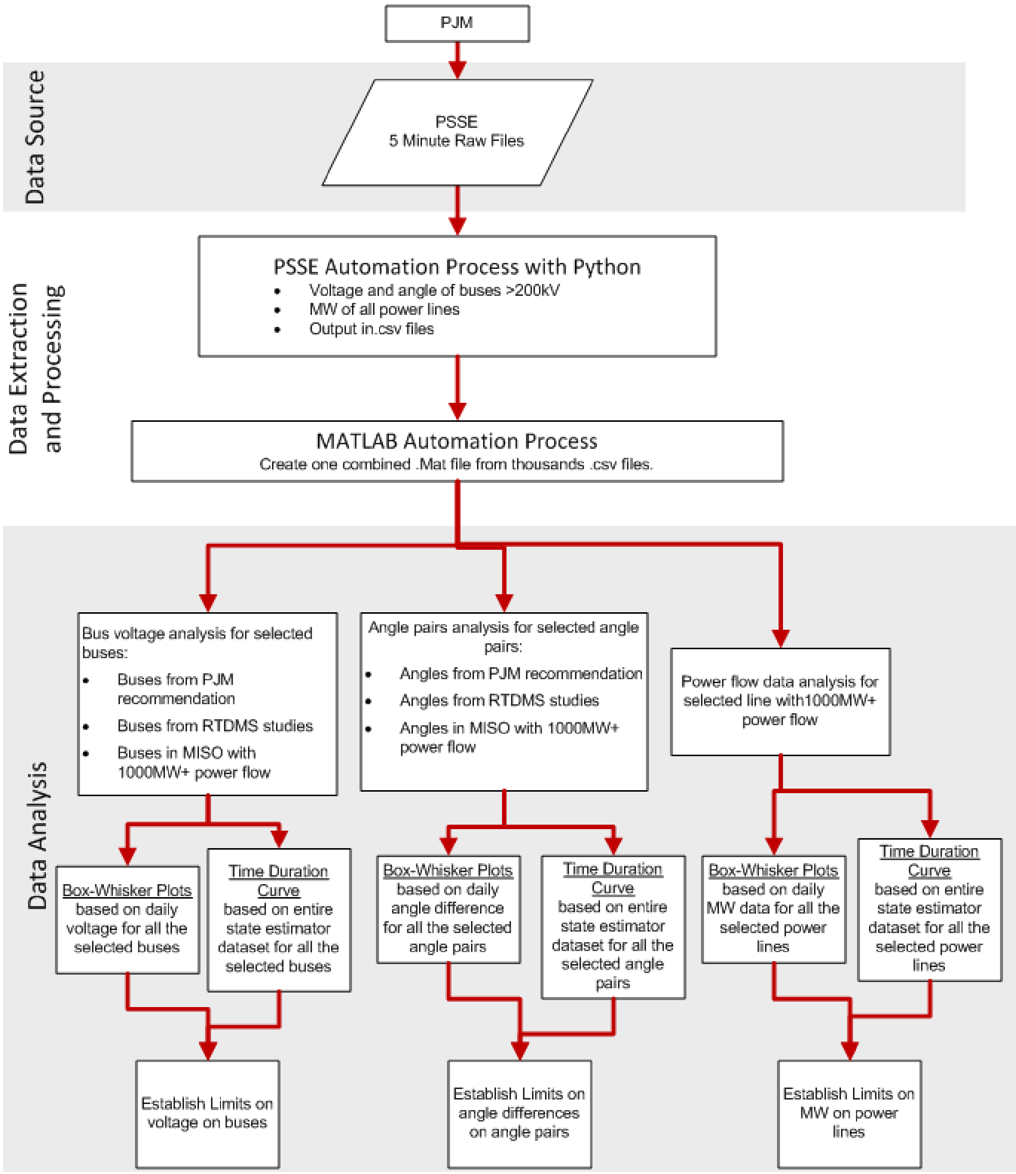


Figure 6: Flowchart of Analysis Procedure for PJM

[1]PJM Baselining Analysis Interim Report was submitted on June 11, 2012. PJM Baselining Outlier Analysis Interim Report was submitted on July 1, 2013

The 5-minute state estimator snapshots were given by PJM in PSSE RAW format. A python script was written to extract voltage, angle and power flow data from all the 200kV+ buses and 1000+ MW paths into 5-minute CSV files. Matlab codes in Figure 6 read CSV files and save the data array into a single voltage, angle and power flow .mat file which can be easily retrieved.

5.2 Angle Pairs Selection

For purposes of statistical analysis, buses, angle pairs were provided by PJM for Eastern Baselining study, according to their key stations, load centers, transmission interfaces, critical high voltage substations, and existing/planned Phasor Measurement Unit (PMU) locations. Figure 7 shows the requested angle pairs in PJM backbone transmission map. There are 35 angle pairs requested to be analyzed by PJM and they are listed in Table 2.

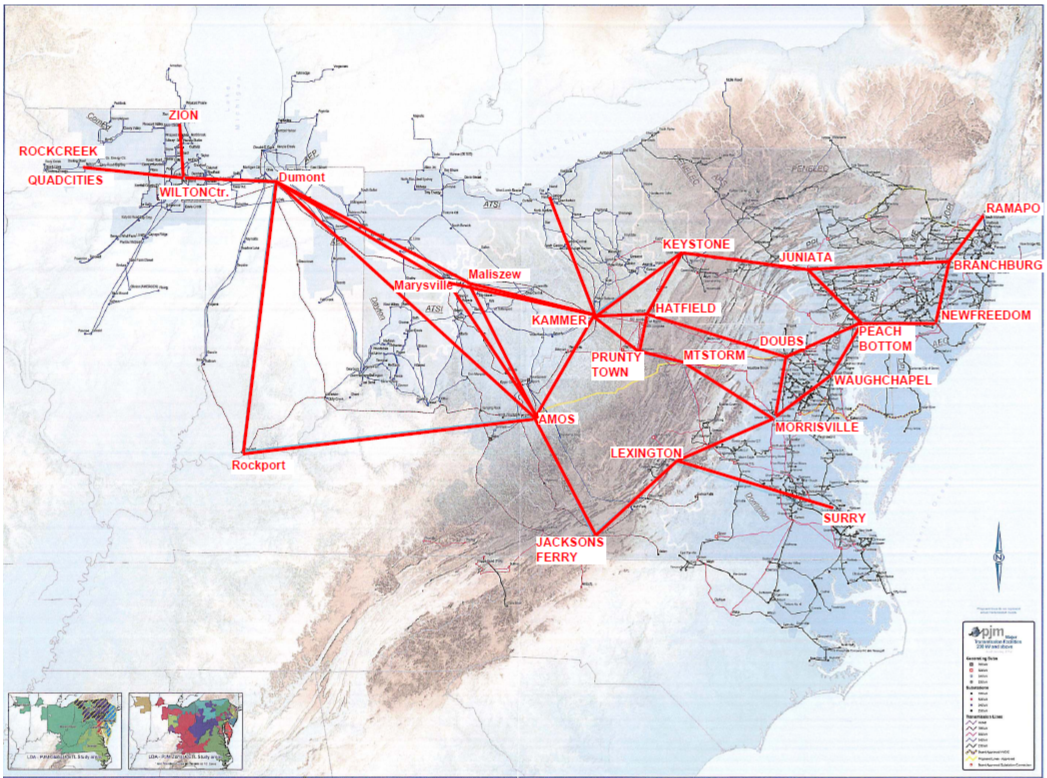


Figure 7: The Map of Angle Pairs Provided by PJM

Table 2: PJM Selected Angle Pairs

Index	From Station	To Station
1	ROCKPORT	DUMONT
2	DUMONT	AMOS
3	ROCKPORT	AMOS
4	AMOS	KAMMER
5	AMOS	JACKSONS FERRY
6	KAMMER	KEYSTONE
7	KAMMER	HATFIELD
8	KAMMER	PRUNTYTOWN
9	JACKSONS FERRY	LEXINGTON
10	HATFIELD	KEYSTONE
11	HATFIELD	PRUNTYTOWN
12	KEYSTONE	JUNIATA
13	HATFIELD	DOUBS
14	PRUNTYTOWN	MTSTORM
15	MTSTORM	MORRISVILLE
16	LEXINGTON	MORRISVILLE
17	LEXINGTON	SURRY*
18	DOUBS	MORRISVILLE
19	PEACH BOTTOM	DOUBS
20	MORRISVILLE	WAUGH CHAPEL
21	PEACH BOTTOM	WAUGH CHAPEL
22	JUNIATA	PEACH BOTTOM
23	JUNIATA	BRANCHBURG
24	PEACH BOTTOM	NEW FREEDOM
25	NEW FREEDOM	BRANCHBURG
26	WILTON *	DUMONT
27	WILTON*	ZION
28	QUAD C*	WILTON
29	DUMONT	MARYSVILLE
30	MARYSVILLE	KAMMER
31	AMOS	MARYSVILLE
32	BRANCHBURG	RAMAPO*
33	DUMONT	MALISZEW*
34	MALISZEW*	KAMMER
35	AMOS	MALISZEW*

*PMU is not installed

5.3 Establish High and Low Range Values for PJM Angle Pairs

The raw data set provided by PJM has many data anomalies. For example, extreme high power flow value and voltage value outside the reasonable data range is found and needs to be removed. These data could be from abnormal conditions, false data or unsolved cases. In order to perform baselining statistical analysis, to find the high and low monitoring values for the PJM angle pairs, Grubbs' test [1] is introduced to remove the abnormal data.

After the abnormal data are removed, the Box-Whisker plot and Time Duration plot are created for each requested angle pairs in order to establish the high and low reference values.

Figure 8 shows an example of the daily angle Box-Whisker plot for angle pair Rockport-Dumont. Figure 9 shows the Rockport-Dumont angle time duration curve.

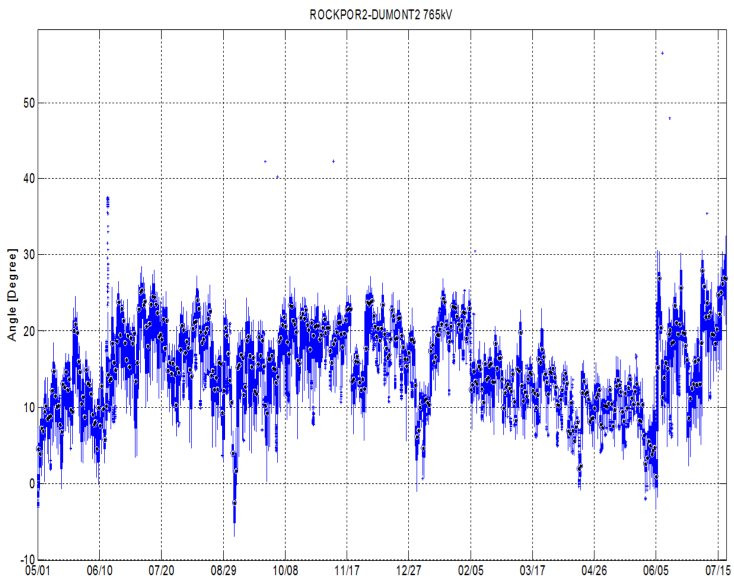


Figure 8: Box-Whisker Plot of Daily Angle of Rockport-Dumount

Box-whisker plot shows the daily angle operation range, daily median and outlier. From this example, it is clear that there is abnormal transients above 30 degree (or under 10 degree) for angle pair Rockport-Dumont. It is suggested the normal range for angle difference can be established around [0,30]. By using the time duration plot, it can be found that angle high/low values [0,30] is around

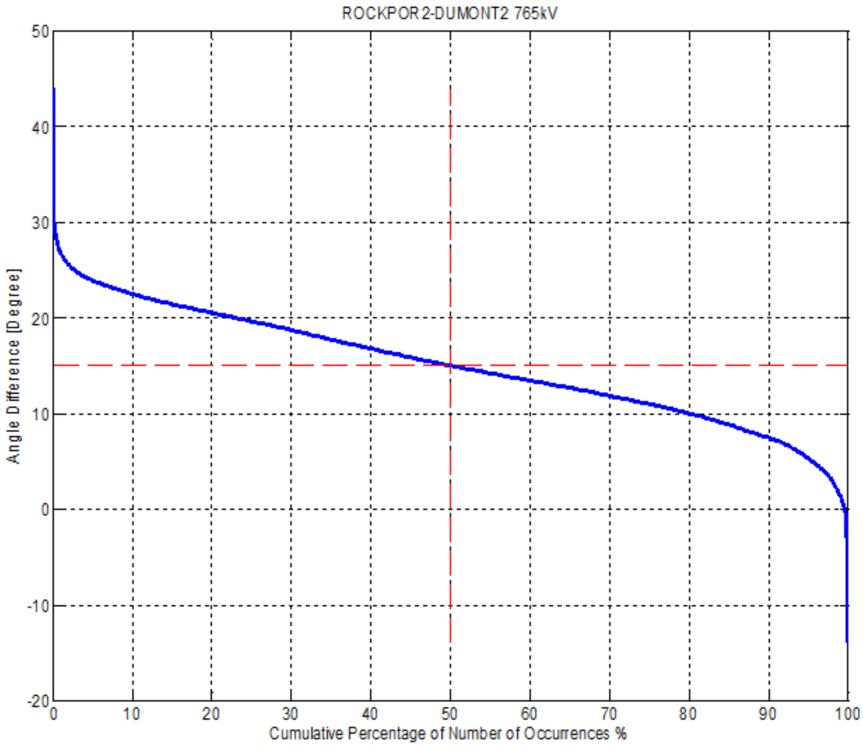


Figure 9: Time Duration Curve: Rockport-Dumont Angle

0.5% and 99.5% percentile. For PJM data, 0.5% and 99.5% of time in the time duration plot are used in setting the high/low values for monitoring and help to avoid abnormal transients.

The complete box-whisker plot and time duration curve for all the selected angle pairs in PJM area are provided in Appendix A.1.

Figure 10 shows another example of the box-whisker chart which is for the PruntyTown-MtStorm angle pair. In this example, by using the box-whisker, questionable dates can be easily identified. In this figure, the behavior of PruntyTown-MtStorm angle values is quite different between the beginning of the May 2010 and the beginning November 2010.

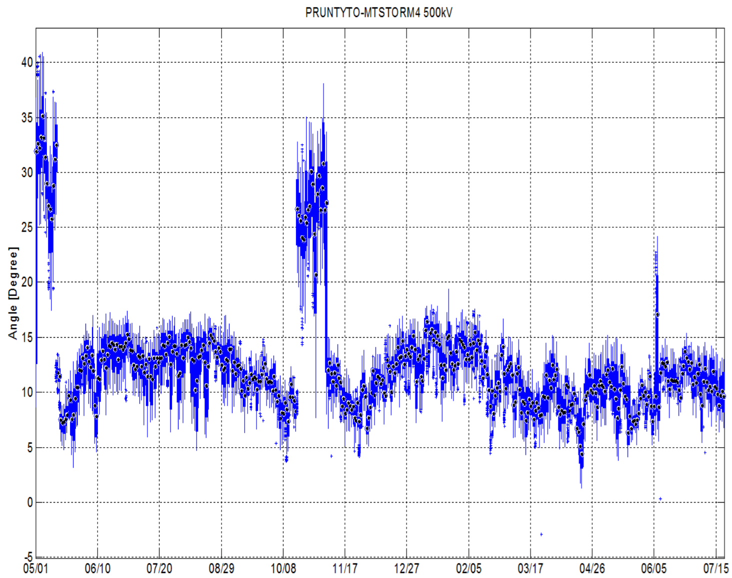


Figure 10: Box-Whisker Plot of Daily Angle of PruntyTown-MtStorm

By checking the one-line diagram of PruntyTown for these questionable data points, it is found the high angle is the result from the disconnection of direct line between PruntyTown-MtStorm which is shown in Figure 11. In this figure, there is direct line between PruntyTown and MtStorm on June 10, 2010. On November 1, 2010, the line disconnection between PruntyTown and MtStorm caused different daily angle magnitude behavior in Figure 10.

After considering both normal conditions of Box-Whisker plot and Time Duration curve, which is shown in Figure 10, suggested high and low values are established and shown in following Figure 12 as two red lines.

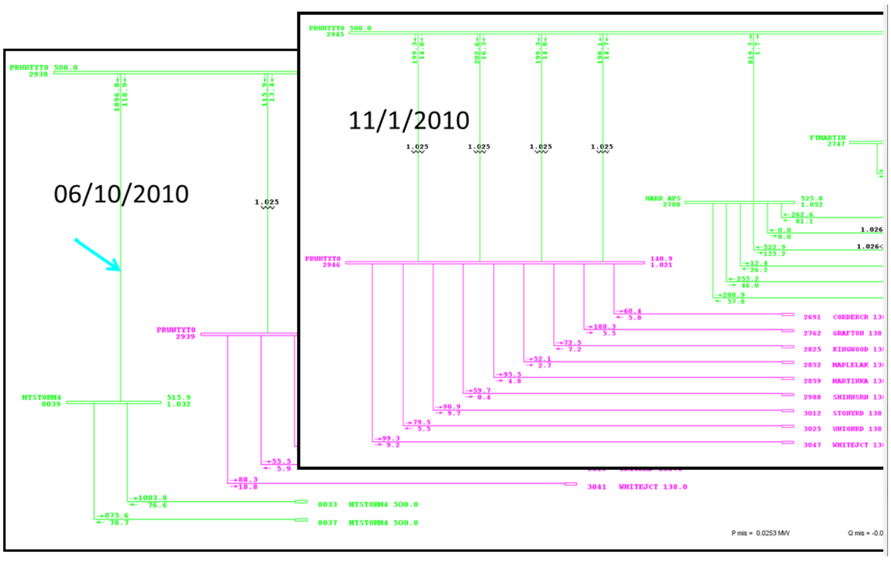


Figure 11: One Line Diagram of PruntyTown

Table 3 lists the high and low angle reference values of all the selected angle pairs.

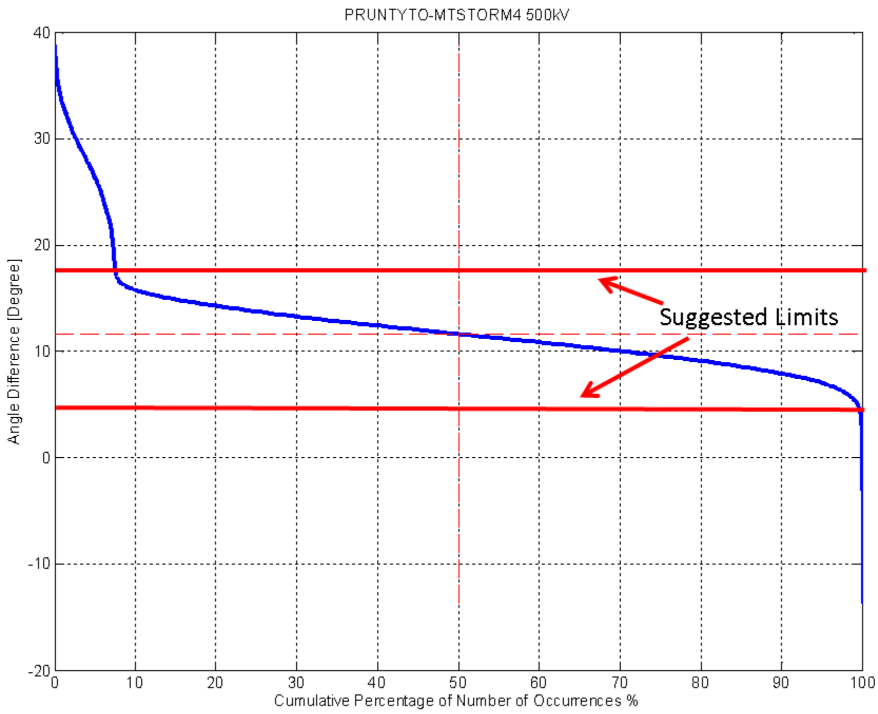


Figure 12: Time Duration Curve: PruntyTown-MtStorm Angle

Table 3: PJM High/Low Angle Monitoring Values for Selected Angle Pairs

Index	From Station	To Station	High Value	Low Value
1	ROCKPORT	DUMONT	30	0
2	DUMONT	AMOS	20	-18
3	ROCKPORT	AMOS	38	2
4	AMOS	KAMMER	20	-4
5	AMOS	JACKSONS FERRY	20	6
6	KAMMER	KEYSTONE	20	-6
7	KAMMER	HATFIELD	12	-4
8	KAMMER	PRUNTYTOWN	11	-1
9	JACKSONS FERRY	LEXINGTON	30	-2
10	HATFIELD	KEYSTONE	11	-6
11	HATFIELD	PRUNTYTOWN	5	-6
12	KEYSTONE	JUNIATA	30	3
13	HATFIELD	DOUBS	40	16
14	PRUNTYTOWN	MTSTORM	18	5
15	MTSTORM	MORRISVILLE	26	3
16	LEXINGTON	MORRISVILLE	26	-5
17	LEXINGTON	SURRY*	28	-9
18	DOUBS	MORRISVILLE	6	-7
19	PEACH BOTTOM	DOUBS	20	-11
20	MORRISVILLE	WAUGH CHAPEL	15	-8
21	PEACH BOTTOM	WAUGH CHAPEL	20	-6
22	JUNIATA	PEACH BOTTOM	15	-3
23	JUNIATA	BRANCHBURG	30	7
24	PEACH BOTTOM	NEW FREEDOM	18	1
25	NEW FREEDOM	BRANCHBURG	12	-3
26	WILTON *	DUMONT	11	-5
27	WILTON*	ZION	13	-6
28	QUAD C*	WILTON*	40	5
29	DUMONT	MARYSVILLE	24	-4
30	MARYSVILLE	KAMMER	10	-7
31	AMOS	MARYSVILLE	16	-2
32	BRANCHBURG	RAMAPO*	9	-4
33	DUMONT	MALISZEW*	25	-4
34	MALISZEW*	KAMMER	7	-6
35	AMOS	MALISZEW*	17	-1

*PMU is not installed

The proposed high value for angle pair monitor is established at the 0.5% of the cumulative percentage of the observations

The proposed low value for angle pair monitor is established at the 99.5% of the cumulative percentage of the observations

An example Boxplot-Whisky chart for ROCKPORT-DUMONT 765kV for all four seasons, weekday/weekend and Onpeak/Offpeak are presented in following Figure 13. In this figure, data are grouped by four seasons. In each season, there are four boxes. Each box represses the data of four subgroups. They are weekday on-peak, weekday off-peak, weekend on-peak, and weekend off-peak. From this figure, it is found most of the outliers appear to happen in summer. High angle difference is shown in summer and winter. The median value of the weekday is relative higher than the median value of the weekend. The median value of the on-peak is relative higher than the value of the off-peak.

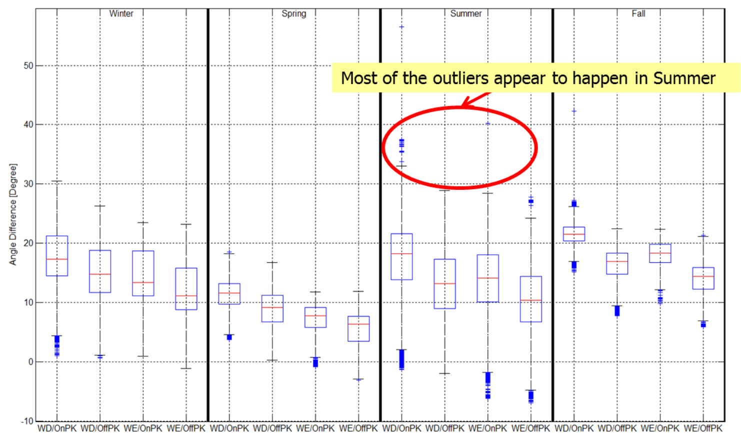


Figure 13: Boxplot-Whisky Chart for ROCKPORT-DUMONT 765kV for Seasonal, Weekday/Weekend, Onpeak/Offpeak Analysis

Figure 14 is the Time Duration plot for ROCKPORT-DUMONT 765kV for all four seasons, weekday/weekend and On-peak/Off-peak. Based on this figure, the operators can set the angle pair range based on the season.

Detailed analysis was conducted for the 35 angle pairs for seasonal, on-peak/off-peak, and weekday/weekend type analysis. Analysis results for all 35 angle pairs are presented in Table 4, 5, 6 and 7.

The complete seasonal, week-day/week-end and On-peak/Off-peak Box-Whisker plots and Time Duration curves for all selected angle pairs in PJM area are provided in Appendix A.2.

Table 4: PJM Summer High/Low Angle Monitoring Values for Selected Angle Pairs

Index	From Station	To Station	WeekDay/OnPeak High Value	WeekDay/OnPeak Low Value	Weekday/OffPeak High Value	Weekday/OffPeak Low Value	Weekend/OnPeak High Value	Weekend/OnPeak Low Value	Weekend/OffPeak High Value	Weekend/OffPeak Low Value
1	ROCKPORT	DUMONT	1	30	0	26	-3	26	-6	24
2	DUMONT	AMOS	-18	22	-11	23	-16	23	-7	24
3	ROCKPORT	AMOS	2	33	10	32	4	32	8	32
4	AMOS	KAMMER	-3	16	-2	13	-3	15	-3	12
5	AMOS	JACKSONS FERRY	6	20	8	20	9	20	9	19
6	KAMMER	KEYSTONE	-5	20	-1	18	-5	18	-1	19
7	KAMMER	HATFIELD	-3	11	1	11	-3	11	2	10
8	KAMMER	PRUNTYTOWN	-1	10	2	10	0	10	3	9
9	JACKSONS FERRY	LEXINGTON	-4	28	11	35	-4	23	11	24
10	HATFIELD	KEYSTONE	-5	11	-5	9	-5	9	-6	10
11	HATFIELD	PRUNTYTOWN	-2	5	-3	5	-2	3	-2	2
12	KEYSTONE	JUNIATA	9	30	8	29	10	29	8	28
13	HATFIELD	DOUBS	19	39	17	35	20	38	17	34
14	PRUNTYTOWN	MTSTORM	5	16	6	18	6	16	7	17
15	MTSTORM	MORRISVILLE	9	28	6	24	10	27	8	23
16	LEXINGTON	MORRISVILLE	4	27	-3	19	1	27	-5	16
17	LEXINGTON	SURRY	1	27	-8	14	-2	27	-7	14
18	DOUBS	MORRISVILLE	-7	5	-5	4	-6	6	-4	5
19	PEACH BOTTOM	DOUBS	-12	17	-13	12	-11	17	-13	17
20	MORRISVILLE	WAUGH CHAPEL	-3	15	-3	11	-3	13	-4	10
21	PEACH BOTTOM	WAUGH CHAPEL	-6	20	-7	14	-5	21	-7	17
22	JUNIATA	PEACH BOTTOM	10	28	10	27	10	28	10	27
23	JUNIATA	BRANCHBURG	0	13	-1	14	0	15	0	14
24	PEACH BOTTOM	NEW FREEDOM	2	17	1	14	3	18	2	15
25	NEW FREEDOM	BRANCHBURG	-1	10	1	10	-1	9	1	8
26	WILTON	DUMONT	-7	15	-1	15	-6	14	1	15
27	WILTON	ZION	-3	15	-5	11	-4	11	-6	8
28	QUAD C	WILTON	-2	34	10	35	-1	35	12	35
29	DUMONT	MARYSVILLE	-7	31	-3	28	-5	30	0	29
30	MARYSVILLE	KAMMER	-10	8	-6	8	-9	8	-4	7
31	AMOS	MARYSVILLE	-1	20	-3	13	-2	17	-4	11
32	BRANCHBURG	RAMAPO	-7	9	-4	8	-5	9	-3	8
33	DUMONT	MALISZEW	-8	31	-4	29	-6	29	0	29
34	MALISZEW	KAMMER	-9	6	-6	6	-8	6	-4	6
35	AMOS	MALISZEW	0	19	-2	13	-1	17	-2	11

The proposed high value for angle pair monitor is established at the 0.5% of the cumulative percentage of the observations

The proposed low value for angle pair monitor is established at the 99.5% of the cumulative percentage of the observations

Table 5: PJM Autumn High/Low Angle Monitoring Values for Selected Angle Pairs

			WeekDay/OnPeak		Weekday/OffPeak		Weekend/OnPeak		Weekend/OffPeak	
Index	From Station	To Station	High Value	Low Value	High Value	Low Value	High Value	Low Value	High Value	Low Value
1	ROCKPORT	DUMONT	17	27	9	22	11	22	6	21
2	DUMONT	AMOS	-5	15	0	18	-1	19	2	20
3	ROCKPORT	AMOS	19	36	13	34	18	36	14	34
4	AMOS	KAMMER	1	9	-2	8	0	8	-3	6
5	AMOS	JACKSONS FERRY	9	15	9	17	9	17	9	19
6	KAMMER	KEYSTONE	-5	12	-8	11	-3	14	-4	12
7	KAMMER	HATFIELD	0	8	0	8	2	10	1	9
8	KAMMER	PRUNTYTOWN	0	8	0	8	1	9	0	9
9	JACKSONS FERRY	LEXINGTON	3	23	2	26	1	23	8	27
10	HATFIELD	KEYSTONE	-6	4	-7	3	-6	4	-7	4
11	HATFIELD	PRUNTYTOWN	-4	3	-4	4	-5	4	-4	3
12	KEYSTONE	JUNIATA	6	24	0	19	8	22	5	21
13	HATFIELD	DOUBS	22	41	12	38	20	39	18	37
14	PRUNTYTOWN	MTSTORM	6	34	5	36	4	32	7	34
15	MTSTORM	MORRISVILLE	3	24	0	23	6	26	3	24
16	LEXINGTON	MORRISVILLE	5	25	-3	22	8	24	0	19
17	LEXINGTON	SURRY	3	22	-3	20	5	21	-1	18
18	DOUBS	MORRISVILLE	-3	6	-2	8	-1	6	1	7
19	PEACH BOTTOM	DOUBS	-2	21	0	28	-5	18	-4	20
20	MORRISVILLE	WAUGH CHAPEL	-7	10	-15	7	-8	8	-12	5
21	PEACH BOTTOM	WAUGH CHAPEL	4	20	2	26	1	19	1	17
22	JUNIATA	PEACH BOTTOM	11	27	5	22	11	25	9	23
23	JUNIATA	BRANCHBURG	-1	15	-4	16	3	19	1	19
24	PEACH BOTTOM	NEW FREEDOM	4	22	1	15	1	15	-1	25
25	NEW FREEDOM	BRANCHBURG	-7	9	-7	9	-9	9	-9	9
26	WILTON	DUMONT	4	22	9	19	7	19	9	19
27	WILTON	ZION	-4	5	-6	3	-5	5	-7	2
28	QUAD C	WILTON	12	38	20	43	10	37	22	38
29	DUMONT	MARYSVILLE	2	17	4	17	5	18	4	16
30	MARYSVILLE	KAMMER	-3	5	-2	5	-1	5	-1	5
31	AMOS	MARYSVILLE	1	8	-2	6	-2	6	-4	4
32	BRANCHBURG	RAMAPO	-2	7	-4	4	-4	9	-5	7
33	DUMONT	MALISZEW	2	19	4	18	5	19	5	17
34	MALISZEW	KAMMER	-3	4	-2	4	-2	4	-1	4
35	AMOS	MALISZEW	2	8	-1	6	-1	6	-3	4

The proposed high value for angle pair monitor is established at the 0.5% of the cumulative percentage of the observations
The proposed low value for angle pair monitor is established at the 99.5% of the cumulative percentage of the observations

Table 6: PJM Winter High/Low Angle Monitoring Values for Selected Angle Pairs

			WeekDay/OnPeak		Weekday/OffPeak		Weekend/OnPeak		Weekend/OffPeak	
Index	From Station	To Station	High Value	Low Value	High Value	Low Value	High Value	Low Value	High Value	Low Value
1	ROCKPORT	DUMONT	5	26	3	24	4	23	0	23
2	DUMONT	AMOS	-3	20	0	21	-1	20	1	20
3	ROCKPORT	AMOS	9	37	12	38	9	37	9	37
4	AMOS	KAMMER	-1	17	-3	14	-1	14	-2	12
5	AMOS	JACKSONS FERRY	7	20	8	21	7	18	7	20
6	KAMMER	KEYSTONE	8	23	6	20	6	22	4	20
7	KAMMER	HATFIELD	4	12	4	12	5	11	5	12
8	KAMMER	PRUNTYTOWN	4	11	5	11	4	11	5	12
9	JACKSONS FERRY	LEXINGTON	3	26	5	26	6	35	10	34
10	HATFIELD	KEYSTONE	-2	13	-4	9	-2	12	-4	10
11	HATFIELD	PRUNTYTOWN	-4	2	-3	2	-3	2	-3	2
12	KEYSTONE	JUNIATA	9	30	4	28	8	32	6	30
13	HATFIELD	DOUBS	19	38	16	38	18	38	15	37
14	PRUNTYTOWN	MTSTORM	5	17	7	17	5	17	6	18
15	MTSTORM	MORRISVILLE	11	25	8	26	9	26	7	23
16	LEXINGTON	MORRISVILLE	8	26	0	25	5	25	-1	19
17	LEXINGTON	SURRY	2	23	-3	23	2	22	-4	18
18	DOUBS	MORRISVILLE	-8	3	-7	6	-6	4	-5	5
19	PEACH BOTTOM	DOUBS	-11	12	-10	15	-14	12	-10	17
20	MORRISVILLE	WAUGH CHAPEL	-1	15	-6	14	-2	15	-5	12
21	PEACH BOTTOM	WAUGH CHAPEL	-7	15	-6	16	-7	14	-5	16
22	JUNIATA	PEACH BOTTOM	12	28	8	25	10	28	9	26
23	JUNIATA	BRANCHBURG	-2	9	-1	10	-1	10	-1	10
24	PEACH BOTTOM	NEW FREEDOM	3	14	0	12	3	15	2	12
25	NEW FREEDOM	BRANCHBURG	2	12	1	10	1	11	1	9
26	WILTON	DUMONT	4	20	7	22	6	20	7	25
27	WILTON	ZION	-3	9	-6	6	-5	7	-7	4
28	QUAD C	WILTON	5	36	15	38	12	35	17	38
29	DUMONT	MARYSVILLE	4	20	6	19	6	20	6	20
30	MARYSVILLE	KAMMER	-3	9	-2	10	-2	9	-3	8
31	AMOS	MARYSVILLE	-1	11	-3	7	-2	8	-3	6
32	BRANCHBURG	RAMAPO	-2	10	-3	7	-2	9	-5	7
33	DUMONT	MALISZEW	4	22	6	24	7	22	7	22
34	MALISZEW	KAMMER	-3	6	-2	6	-2	7	-3	7
35	AMOS	MALISZEW	0	14	-2	11	-2	9	-3	7

The proposed high value for angle pair monitor is established at the 0.5% of the cumulative percentage of the observations
The proposed low value for angle pair monitor is established at the 99.5% of the cumulative percentage of the observations

Table 7: PJM Spring High/Low Angle Monitoring Values for Selected Angle Pairs

Index	From Station	To Station	WeekDay/OnPeak High Value	WeekDay/OnPeak Low Value	Weekday/OffPeak High Value	Weekday/OffPeak Low Value	Weekend/OnPeak High Value	Weekend/OnPeak Low Value	Weekend/OffPeak High Value	Weekend/OffPeak Low Value
1	ROCKPORT	DUMONT	5	17	2	16	0	12	-2	12
2	DUMONT	AMOS	-13	18	-6	16	-1	21	1	18
3	ROCKPORT	AMOS	1	26	7	28	8	29	7	25
4	AMOS	KAMMER	-3	29	-2	22	0	20	-1	18
5	AMOS	JACKSONS FERRY	5	19	7	19	8	17	8	15
6	KAMMER	KEYSTONE	-12	18	-7	17	-1	18	-2	15
7	KAMMER	HATFIELD	-6	9	-3	9	0	10	0	9
8	KAMMER	PRUNTYTOWN	-2	8	-1	9	1	9	0	8
9	JACKSONS FERRY	LEXINGTON	-10	25	10	36	4	24	14	25
10	HATFIELD	KEYSTONE	-6	11	-4	10	-1	11	-2	9
11	HATFIELD	PRUNTYTOWN	-6	4	-6	4	-8	3	-6	3
12	KEYSTONE	JUNIATA	3	28	4	21	3	23	4	20
13	HATFIELD	DOUBS	14	42	15	39	18	42	15	36
14	PRUNTYTOWN	MTSTORM	2	38	6	39	5	37	6	35
15	MTSTORM	MORRISVILLE	5	22	-1	18	5	27	2	25
16	LEXINGTON	MORRISVILLE	-1	27	-9	19	-1	23	-7	14
17	LEXINGTON	SURRY	-1	32	-12	21	-3	23	-9	15
18	DOUBS	MORRISVILLE	-5	4	-4	4	-4	4	-3	4
19	PEACH BOTTOM	DOUBS	-9	21	-10	18	-7	17	-7	13
20	MORRISVILLE	WAUGH CHAPEL	-7	10	-9	9	-6	9	-7	8
21	PEACH BOTTOM	WAUGH CHAPEL	-4	17	-5	15	-2	14	-3	9
22	JUNIATA	PEACH BOTTOM	4	27	6	27	7	28	8	28
23	JUNIATA	BRANCHBURG	-4	12	-2	13	-1	13	-1	12
24	PEACH BOTTOM	NEW FREEDOM	0	16	0	14	1	15	1	14
25	NEW FREEDOM	BRANCHBURG	1	19	0	15	1	14	1	15
26	WILTON	DUMONT	-7	18	0	21	4	16	7	16
27	WILTON	ZION	-4	9	-5	5	-6	8	-6	4
28	QUAD C	WILTON	3	36	16	37	15	35	18	36
29	DUMONT	MARYSVILLE	-6	29	-1	23	5	20	5	18
30	MARYSVILLE	KAMMER	-7	19	-5	17	-1	12	-2	11
31	AMOS	MARYSVILLE	0	15	-1	12	-2	8	-2	7
32	BRANCHBURG	RAMAPO	-2	8	-3	6	-2	5	-3	4
33	DUMONT	MALISZEW	-7	31	-1	25	7	25	7	20
34	MALISZEW	KAMMER	-7	8	-4	8	-2	10	-2	9
35	AMOS	MALISZEW	1	28	-1	20	-1	11	-1	9

The proposed high value for angle pair monitor is established at the 0.5% of the cumulative percentage of the observations
The proposed low value for angle pair monitor is established at the 99.5% of the cumulative percentage of the observations

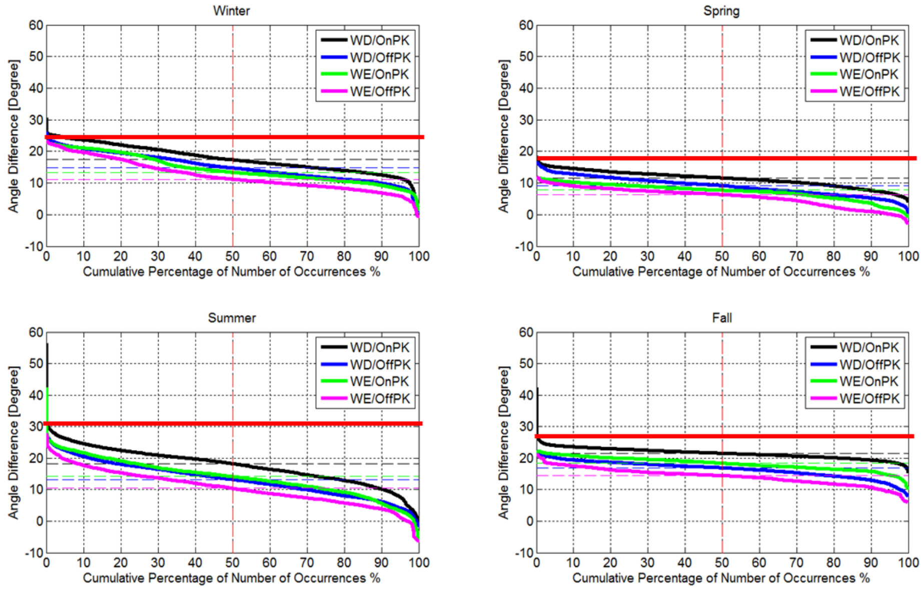


Figure 14: Time Duration Plot for ROCKPOR-DUMONT 765kV for Seasonal, Weekday/Weekend, Onpeak/Offpeak Analysis

5.4 Conclusions and Observations

This section of the report presents the "Statistical analysis" that has been conducted on 35 angle pairs suggested by PJM using their five minute state estimator data. Based on this statistical analysis, range of these angle pairs is suggested. Additional analysis has been conducted to establish the ranges based on seasons, weekday/weekends and peak/off-peak periods. The analysis has shown that the range is higher during summer as the system is more stressed. Analysis has also been conducted for some outliers that do not fall with in the suggested range. Analysis showed that most of the outliers are in summer under stressed conditions and were caused by SE not solving. The results of the analysis are available for use in operation.

6 DATA ANALYSIS FOR MISO FOOTPRINT[1]

6.1 Data Extraction and Analysis Procedure

Figure 15 below illustrates the flow of data as well as the process that are involved in performing the baselining analysis for the MISO area.

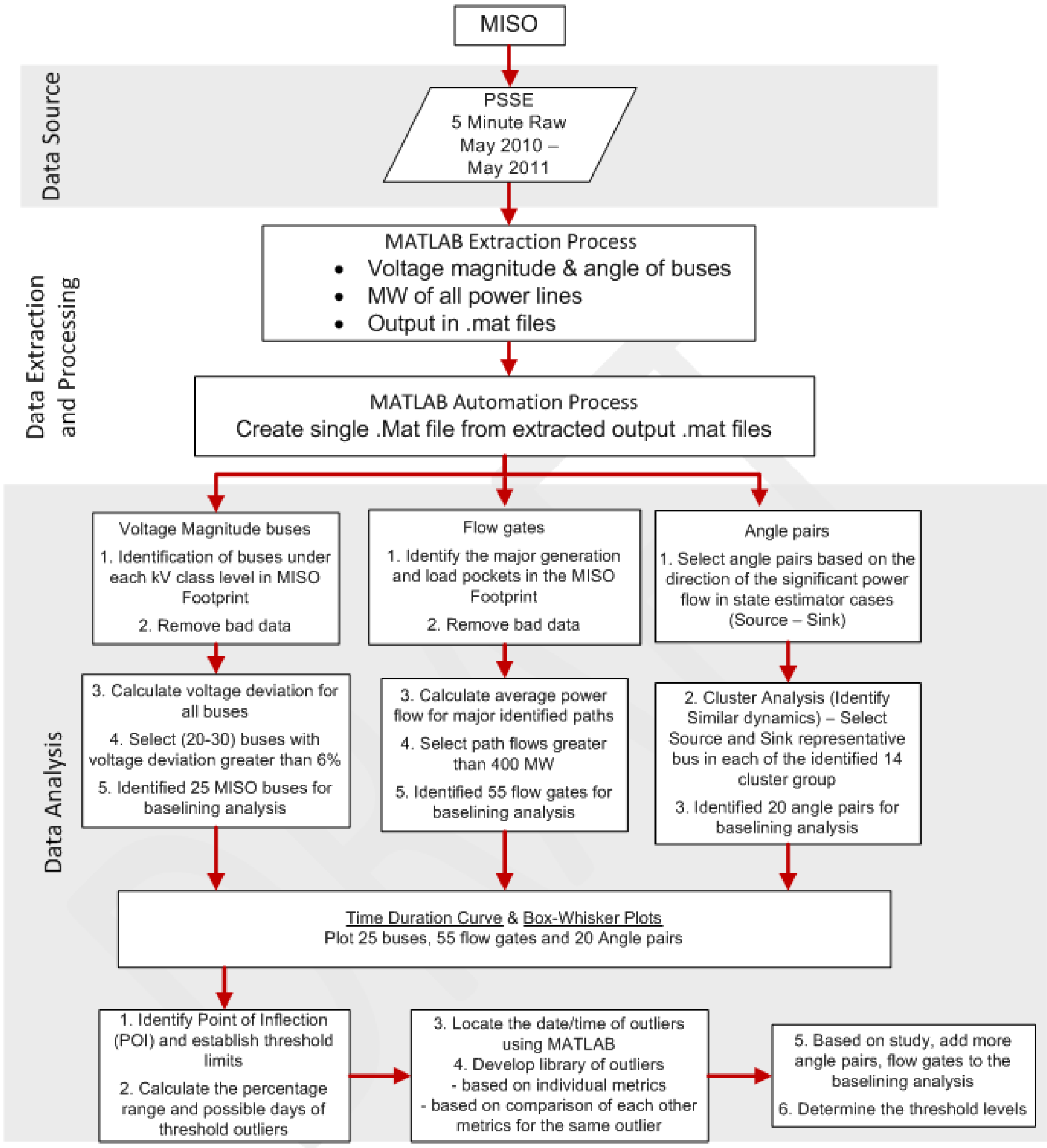


Figure 15: Flowchart of Analysis Procedure for MISO

[1]MISO Baselining Analysis Interim Report was submitted on December 19, 2012. MISO Baselining Outlier Analysis Interim Report was submitted on July 16, 2013

The 5-minute state estimator snapshots were given by MISO in PSSE RAW format. A python script was written to extract voltage, angle and power flow data from all the 200kV+ buses and 1000+ MW paths into 5-minute CSV files. Matlab codes in Figure 15 read CSV files and save the data array into a single voltage, angle and power flow .mat file which can be easily retrieved. Matlab was also used as a tool to extract the data for calculation of statistics and plotting. Time Duration charts are used to identify the outliers, establish high/low monitoring reference values.

6.2 Angle Pairs Selection

The candidate angle pairs selection is based on the direction of the significant power flow (MW>400MW). The angle pairs start with the sources and end with sink. There are total of 16 angle pair candidates identified in MISO foot print. Figure 16 shows the angle pair candidates in the MISO map.

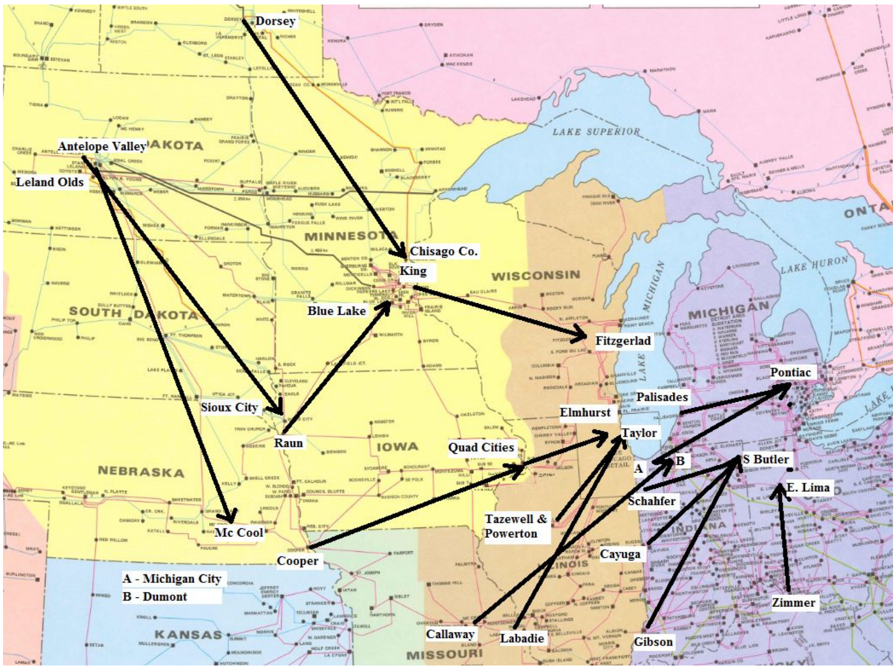


Figure 16: MISO Angle Pairs Candidates for Eastern Baselining Study

Then the clustering technique is used to select a representative bus. Clustering analysis is performed between the entire available buses angle signal to identify signals groups which have similar trend/behavior. Bus voltage angles with correlation coefficient greater than 0.9 will be considered as a cluster. Figure 17 shows an example of Clustering Analysis Example. In this example, the voltage angles of four buses, Antelope Valley, Leland Olds, Charlie Creek and Belfield show identical dynamics. A representative bus is selected with PMU installed preference for a cluster.

An example detailed map with buses grouped by the clustering method and installed PMU is presented Figure 18. In this figure, a black circle with several buses represents a cluster. Different clusters can be identified by the color of the squares. The black triangle ▲ in the figure represents a bus with PMU installed. A bus with PMU installed has a preference in the selection of the representative bus for the cluster.

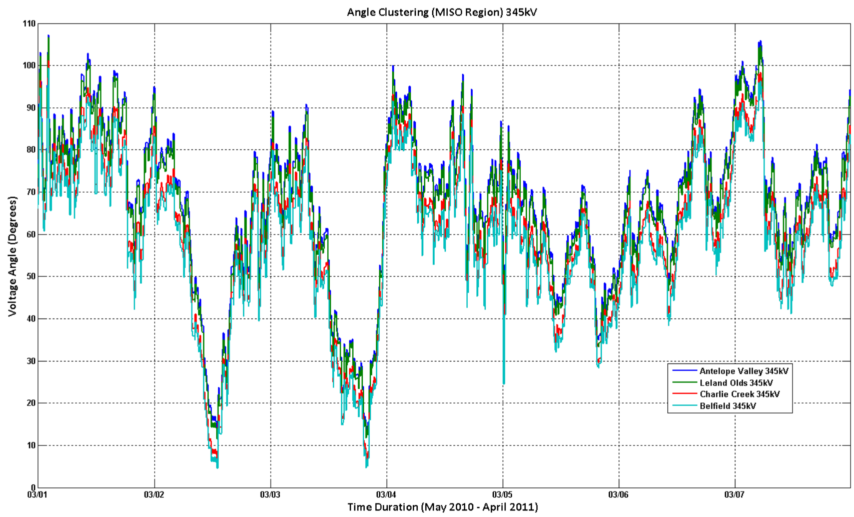
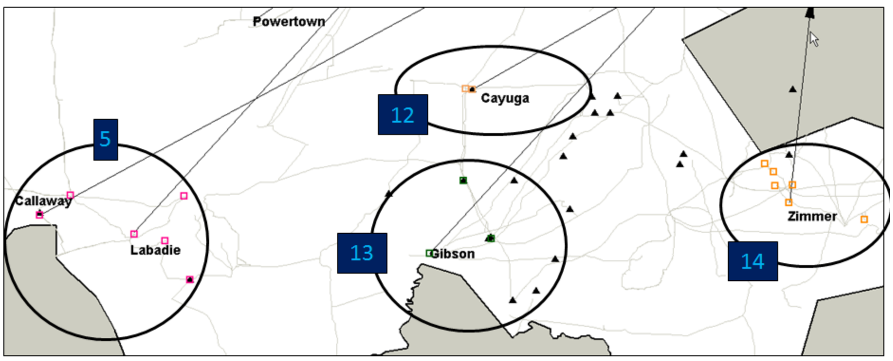


Figure 17: Clustering Analysis Example



▲ PJM is installed

Figure 18: Example Showing Use of Clustering for Grouping Nearby Busses and for Selecting a "Representative Bus"

The Table 8 shows the summary of the selected angle pairs for MISO Baseline study. There are total of 20 angle pairs that are suggested for monitoring. One of these is a 500 kV bus, the rest are 345 kV busses. MISO system is predominantly a 345 kV system.

Table 8: MISO Angle Pair List for Study

Angle Pair Index	From Bus	To Bus	basekV (kV)
1	Antelope Valley	Raun*	345
2	Antelope Valley	Cooper Station	345
3	Raun*	Asking	345
4	Cooper Station	Raun*	345
5	Dorsey*	Chisago	500
6	Cooper Station	Callaway*	345
7	Asking	Arcadian	345
8	Cooper Station	Quad Cities	345
9	Quad Cities	Taylor	345
10	S Butler	Dumont	345
11	Zimmer	S Butler	345
12	Dumont	Pontiac	345
13	Callaway*	Dumont	345
14	Arcadian	Taylor	345
15	Power Town	Dumont	345
16	Callaway*	Cayuga*	345
17	Cayuga*	Gibson	345
18	Gibson	S Butler	345
19	Cayuga*	Dumont	345
20	Taylor	Dumont	345

*PMU is installed

6.3 Establish High and Low Range Values for MISO Angle Pairs

Figure 2 discussed earlier, showed that the MISO state estimator data received had lot of missing data especially for the days after middle of January 2011. For effective base-lining analysis, it is desirable to have a minimum of complete one year data so as to capture the data variation of all seasons. Seasonal analysis cannot be performed if data for entire year is not available. The calculation of the data availability for MISO data showed the data availability of less than 35%. With this data availability, the confidence value in the suggested range and reference value will be low unless the range is widened. This is necessary to avoid un-necessary alarms/alerts to the operators. It is recommended that in order to improve the accuracy and correctness of the reference values and identified outliers analysis be conducted with data availability of higher than 95% availability.

To establish the high/low monitoring reference values for the selected angle pairs, Box-Whiskers charts and Time Duration plots are created. Daily phase angle values are depicted as box-and-whisker plots in order to display the large amount of data in an effective way. Time Duration plot is also introduced to give a visual impression of the data distribution. It is an estimate of the probability distribution of a continuous variable. As discussed earlier, these plots help to identify the proportion of cases that fall into each of several box-whisker categories and quickly establish the high/low monitoring reference values.

Figure 19 shows Time Duration curve for the angle of Antelope-Raun and Figure 20 shows the Box-Whisker chart for Antelope-Raun daily angle. The Time Duration plot gives a visual impression of the distribution of the angle value. Due to less than 35% data availability and in order to avoid tight reference value range to the operators, some margin is given. The blue line and the red lines shown in Figure 19 are the points of inflection and suggested high/low monitoring reference values. The complete Box-Whisker charts and Time Duration curve for all the selected MISO pairs can be found in Appendix A.3.

Box-whisker plot shows the daily angle operation range, daily median and outlier. By using the box-whisker chart, the questionable date can be quickly identified. There are some abnormal angle values in the Figure 20 which are outside the suggested reference range. By checking the one-line diagram of Antelope for these questionable dates, we found the atypical angle is the result from the lines outage which is shown in Figure 21 and 22.

Table 9 presents data availability over almost one year period and suggested high and low monitoring reference values for all selected MISO angle pairs. The number of days of exceeding threshold is also provided.

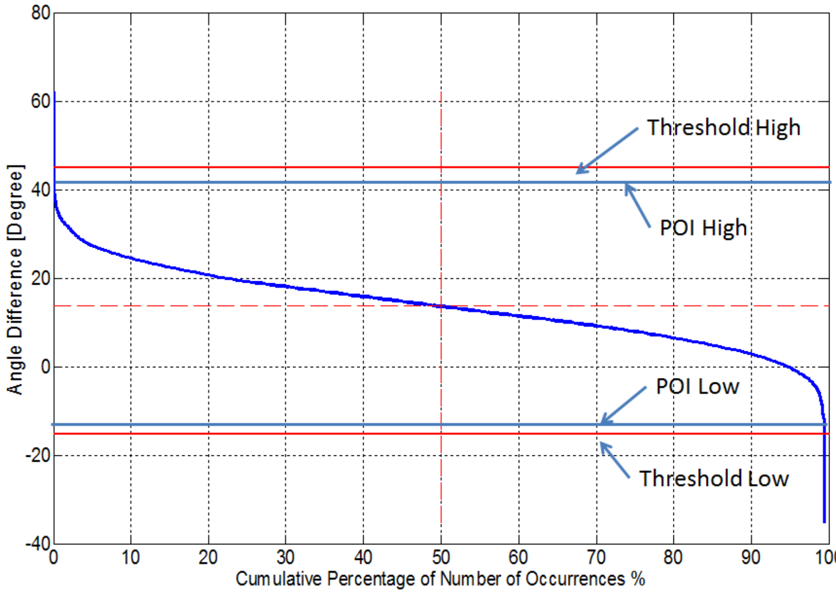


Figure 19: Time Duration Curve: Antelope-Raun 345kV Angle Difference

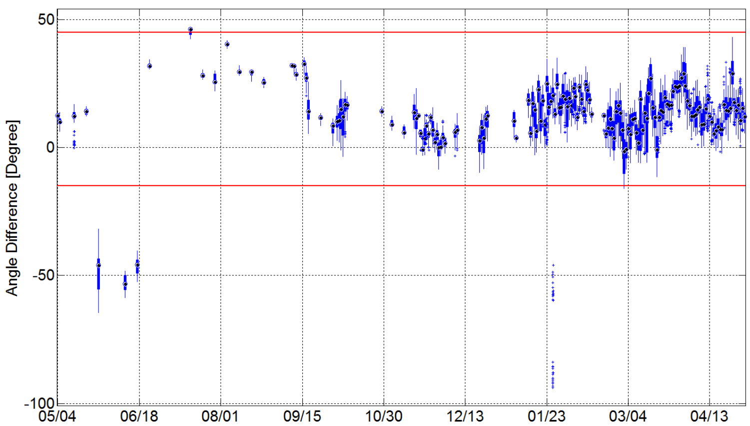


Figure 20: Box-Whisker Plot of Daily Angle between Antelope and Raun

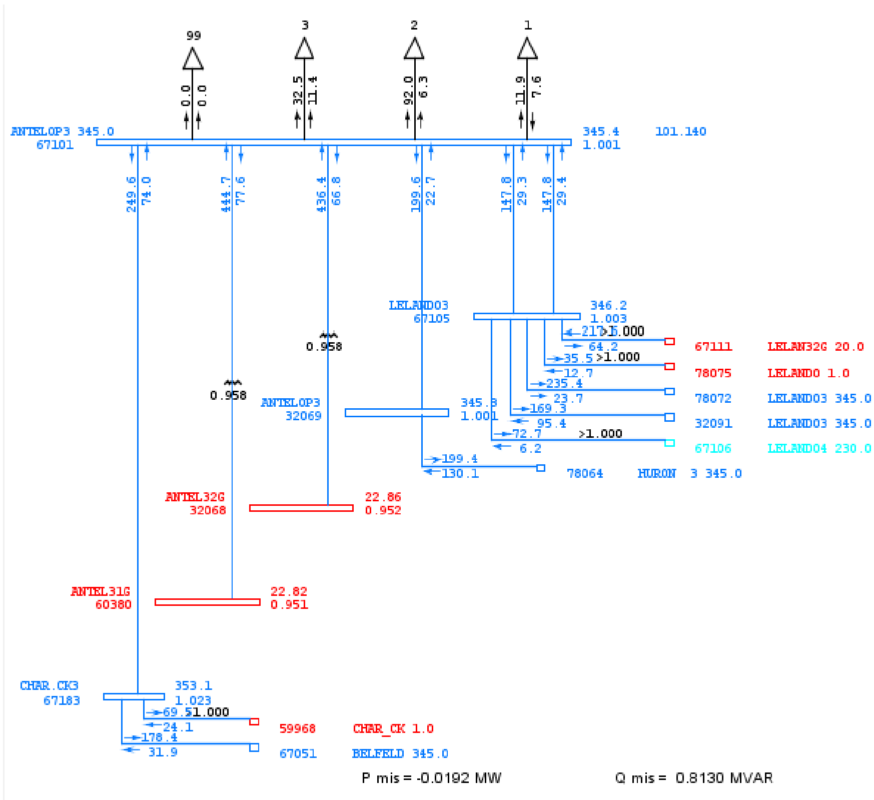


Figure 21: One Line diagram of Antelope in Normal Condition

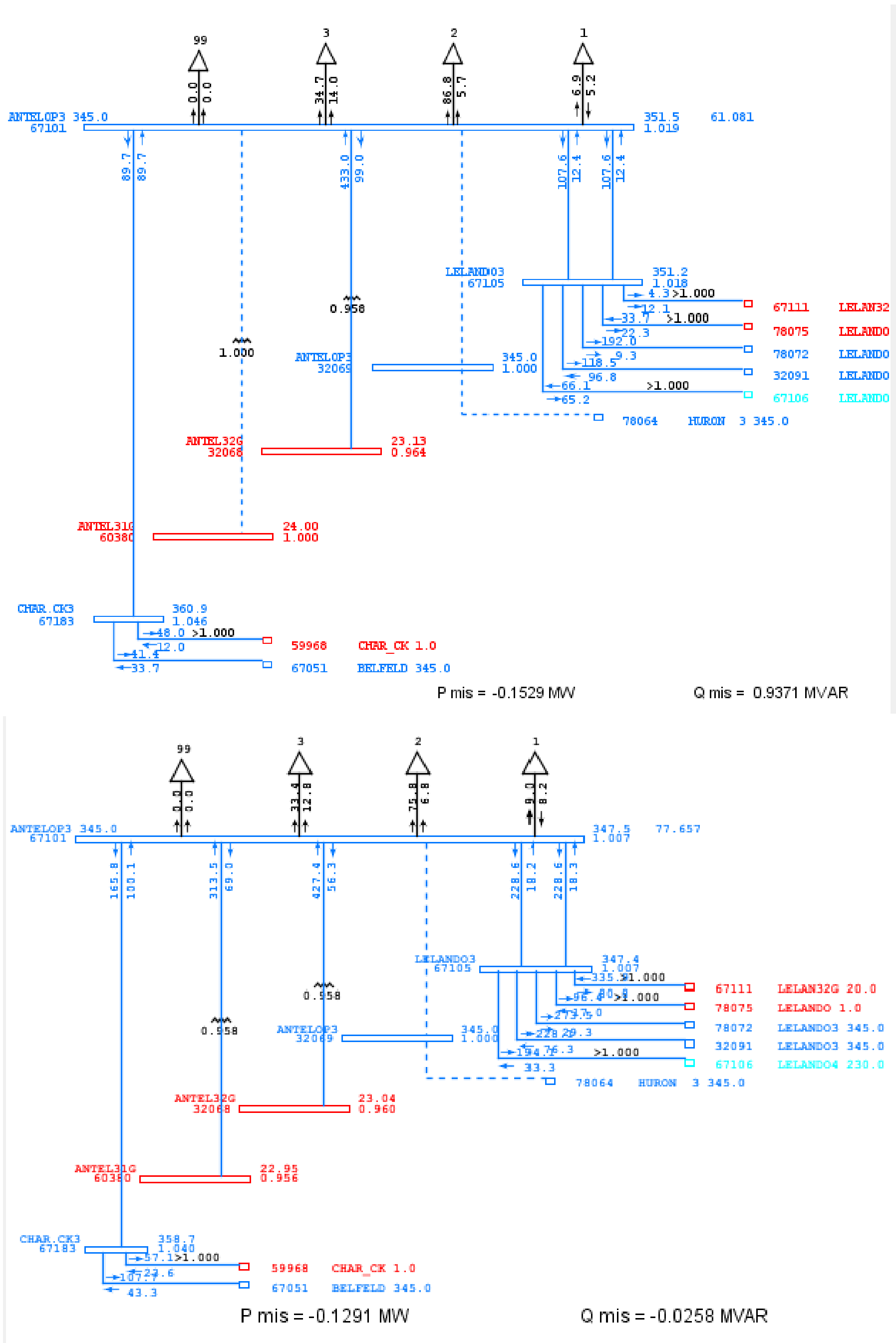


Figure 22: One Line diagram of Antelope in Dates with Atypical Angle Value (05/26/2010, 06/09/2010)

Table 9: Proposed High/Low Values for the Selected Angle Pairs Monitoring in MISO Footprint

Index	From	To	BaseKV	Availability	Low Value	High Value	Number of Days Exceeding
1	Antelope Valley	Raun*	345	34%	-15	45	6
2	Antelope Valley	Cooper Station	345	34%	-50	50	5
3	Raun*	Asking	345	34%	-10	45	0
4	Cooper Station	Raun*	345	34%	-20	25	0
5	Dorsey*	Chisago	500	29%	-5	50	2
6	Cooper Station	Callaway*	345	34%	-20	45	0
7	Asking	Arcadian	345	34%	-50	60	0
8	Cooper Station	Quad Cities	345	34%	-5	45	1
9	Quad Cities	Taylor	345	34%	-5	65	4
10	Dumont	S Butler	345	34%	5	20	1
11	Zimmer	S Butler	345	34%	-5	30	0
12	Dumont	Pontiac	345	34%	10	50	9
13	Callaway*	Dumont	345	34%	0	65	2
14	Arcadian	Taylor	345	34%	-25	65	1
15	Power Town	Dumont	345	34%	5	40	5
16	Callaway*	Cayuga*	345	34%	-5	50	3
17	Gibson	Cayuga*	345	34%	-10	20	3
18	Gibson	S Butler	345	34%	10	55	3
19	Cayuga*	Dumont	345	34%	0	25	1
20	Taylor	Dumont	345	34%	-15	30	5

*PMU is installed
The proposed high value for angle pair monitor is established at the 0.5% of the cumulative percentage of the observations
The proposed low value for angle pair monitor is established at the 99.5% of the cumulative percentage of the observations

6.4 Outlier Analysis

There are total 43 outliers that were analyzed selected based on the bus voltage magnitude and angle which can be found in the Appendix A.4. The counts of outliers are shown in Table 10 grouped by the possible reason for the outage case. Out of these 43 outliers, there are 16 outliers with no reason found. Fourteen(14) outlier were caused by line outages and 13 outliers were caused by load changes. Based on this "Outlier Analysis Study",it is felt that phase angle base-lining results can be used to establish range to monitor the system stress and abnormal operating conditions. By establishing the range properly, the operators can be alerted under stressed system conditions or when abnormal situation (line outage, load changes) occur. A very tight range will result in too many alarms and is not advisable.

Table 10: MISO Outlier Counts

No Reasone Found	Line outage cases	Load change cases	Total
16	14	13	43

Table 11 shows an example of a heavy-loaded line trip which is one of the 43 outliers listed in the Appendix A.4. From this table, the date of the outlier, affected bus, reason and cause of the outlier are given.

The reason for selecting the outlier is the drop of bus voltage at bus 08NUCOR 345kV, which drops to 332kV as shown in Figure 23. At the same time, phase

Table 11: Example of a MISO Outlier because of Heavy-Loaded Line Trip

Index	Date of Outlier	Affected Bus	Voltage Level (kV)	Cause of Outlier	Potential Cause
18	2/4/2011	08NUCOR	345	VM drop to 332kV	The outage of 08NUCOR-08CAYUGA 345 kV line was identified to be the cause for the voltage fluctuation at 08NUCOR 345 kV bus. The flows in the lines appear to be genuine.

angle difference between 08CAYUGA 345kV and 05DUMONT 345kV exceeded the reference suggested range as shown in Figure 24.

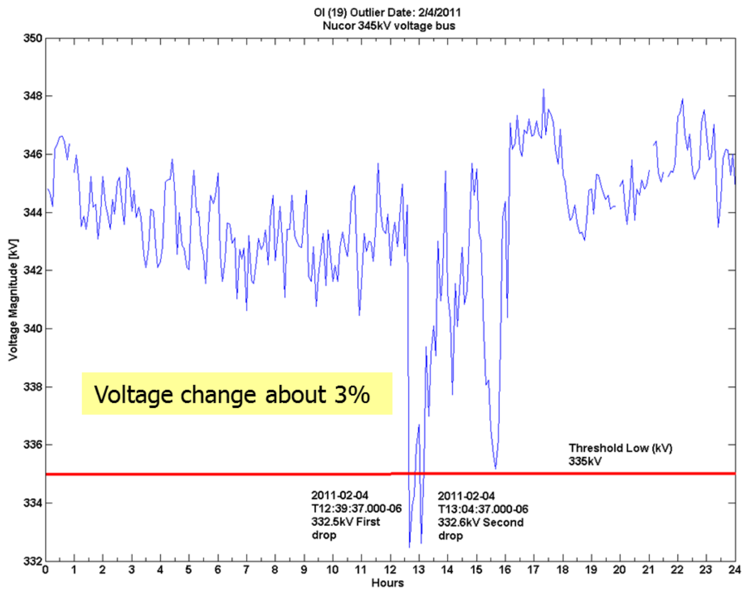


Figure 23: One Line diagram of Antelope in Normal Condition

By checking the one-line diagram, there is a line trip event between bus 08CAYUGA 345kV and 08NUCOR 345kV which is shown in Figure 25.

Figure 24: One Line diagram of Antelope in Normal Condition

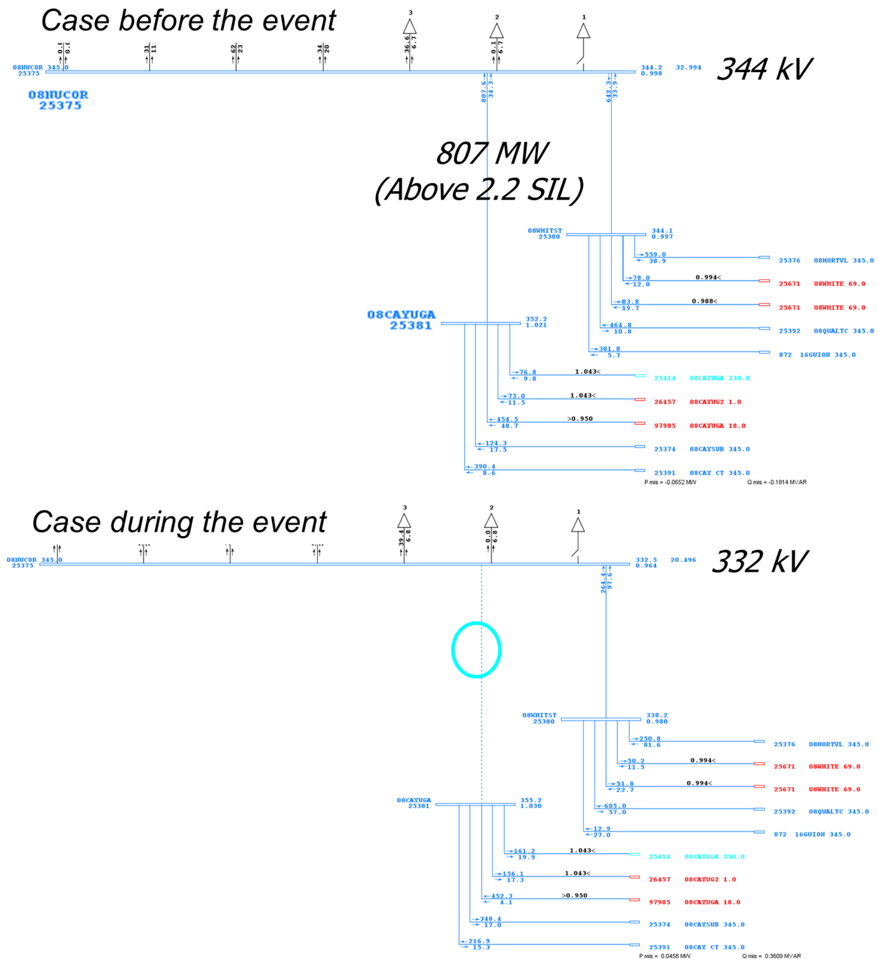


Figure 25: One Line Diagram Before and After a Line Outage for an Example Outlier

6.5 Conclusions and Observations

This section presents the statistical analysis conducted on the data extracted from the SE data provided MISO. There are total of 16 angle pair candidates recommended based on power flow and clustering studies for MISO area. Reference range for monitoring is proposed for each of the sixteen angle pairs. Since the data availability, is very low (35%), seasonal analysis cannot be performed. Also, the confidence level on the suggested range is low and it is recommended to perform the analysis again with higher data availability to have better confidence in the suggested values.

There are total 43 outliers that were analyzed. These outliers were caused by multiple reasons and sixteen cases were caused by system outages. Based on the outlier analysis study, it is noted that suggested phase angle ranges could be used to monitor the system stress and abnormal operating conditions and alert operators when ranges are exceeded. The results were provided to MISO engineers, discussed with them and are being used by them.

7 DATA ANALYSIS FOR NYISO FOOTPRINT[1]

7.1 Data Extraction and Analysis Procedure

Figure 26 below illustrates the flow of data as well as the process that are involved in performing the baselining analysis for the NYISO area.

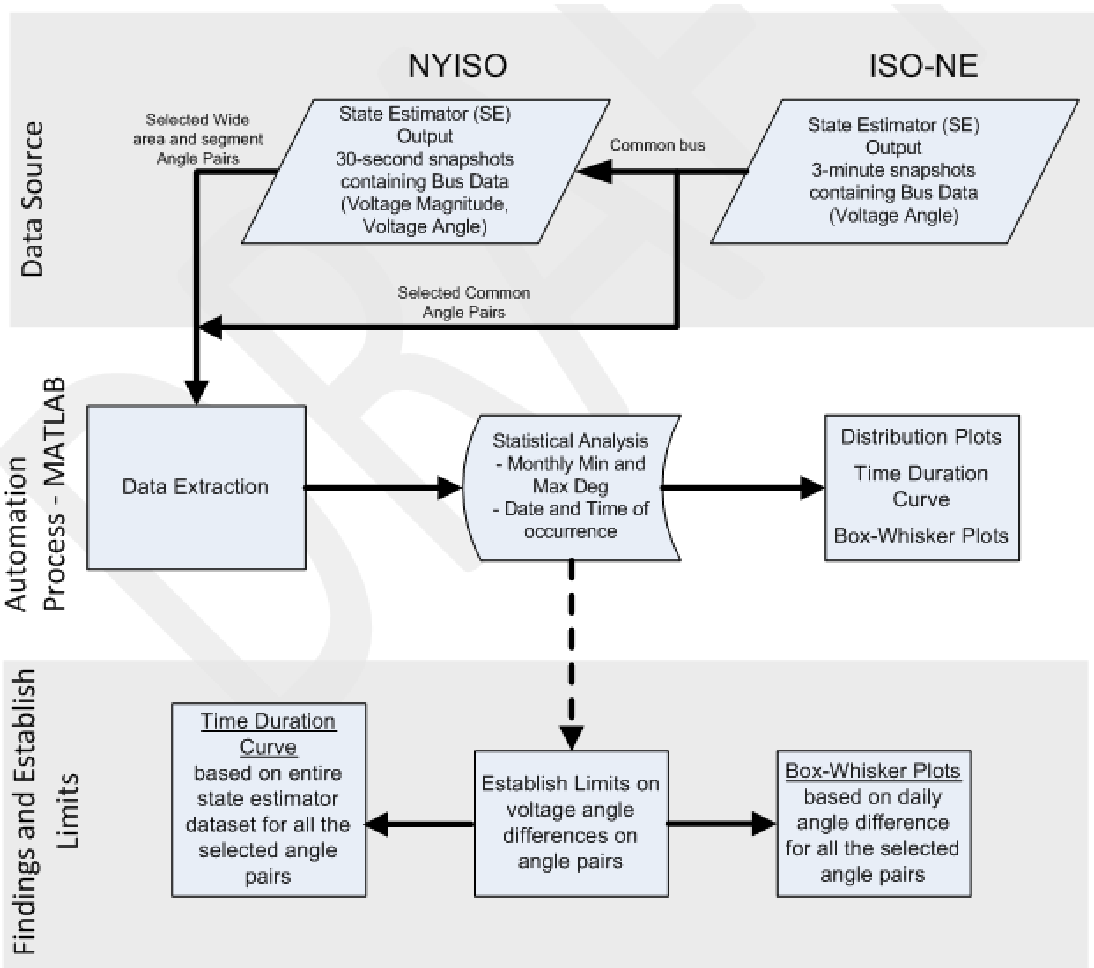


Figure 26: Flowchart of Analysis Procedure for NYISO

NYISO provided 30-second state estimator snapshots containing bus voltage magnitude and phase angle data in Microsoft Excel worksheet format. The Excel work sheet was loaded into MATLAB for analysis and selected angle pairs were identified to extract the voltage angle signals. Then, MATLAB saves the data array into a single voltage magnitude and angle .mat file which can be easily retrieved. Matlab was also used as a tool to extract the data for calculation of statistics and

[1]NYISO Baselining Analysis Interim Report was submitted on March 25, 2013

plotting. Time duration charts are used to identify the outliers, establish high/low monitoring values and determine the exceeding threshold levels.

7.2 Angle Pairs Selection

NYISO provided the NYCA 345-230 kV One-line diagram indicating the region of boundary and load pockets. The total NYISO generation is approximately 37,700 MW and peak demand is approximately 33,500 MW.

Figure 27 shows the major NYISO load pocket (Sprainbrook / Dunwoodie South) whereas Figure 28 and 29 show the major generation in the NYSIO region.

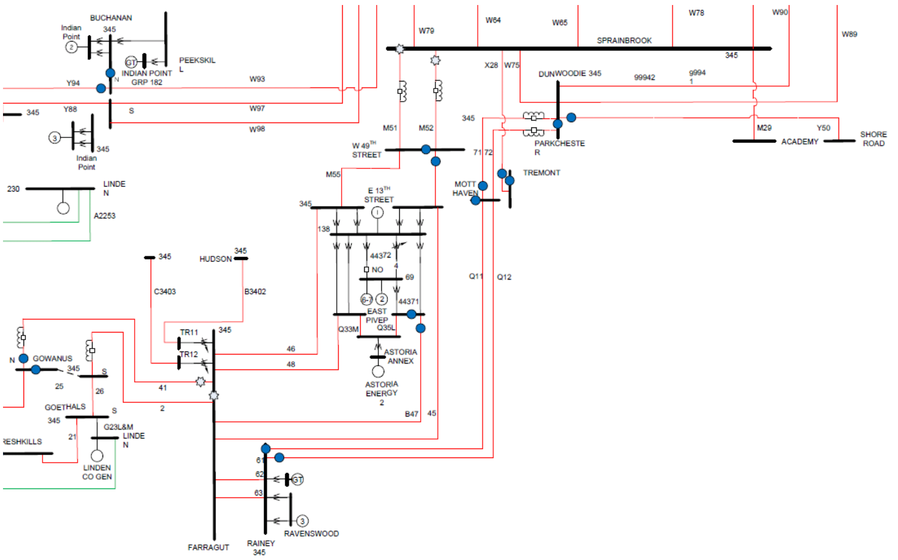


Figure 27: NYISO Major Load Pocket (SprainBrook/Dunwoodie South)
Note: figure is portion of the NYCA 345-230 kV One-line diagram provided by NYISO.

The determination of angle pairs is based on the one-line diagrams, the available NYISO buses in output dataset of the state estimator and key statistics. The selection of angle pairs follows the major generation-load pockets in NYISO. Table 12 shows the list of buses closer to major generation and load.

The angle pairs are divided into two categories in the NYISO footprint:

- NYISO wide area angle pairs. (See Table 13 and Figure 30)
- NYISO segment angle pairs (See Table 14)

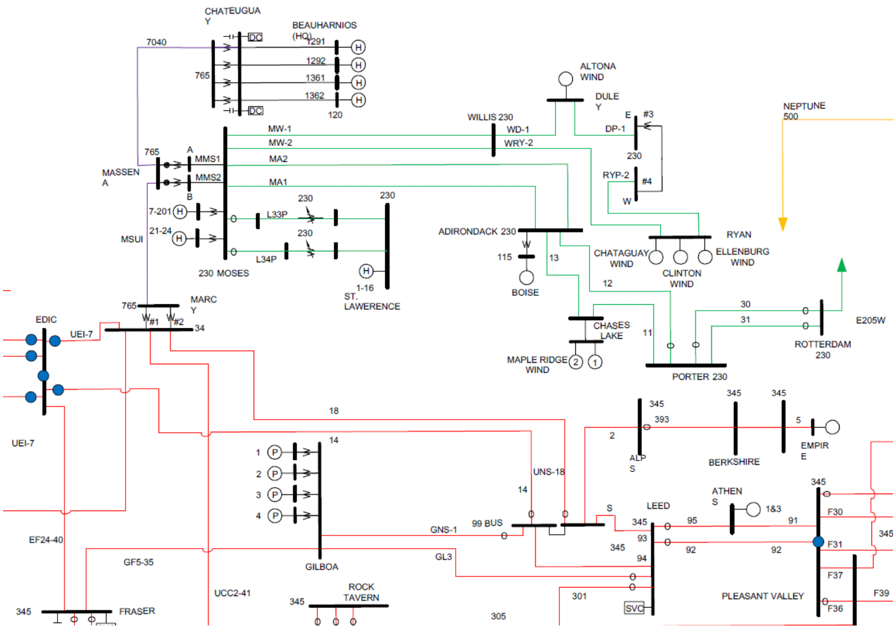


Figure 28: NYISO Generation-1 (CHATEUGUA/MASSENA/MARCY)
Note: figure is portion of the NYCA 345-230 kV One-line diagram provided by NYISO.

Table 12: NYISO Buses Near to Major Generation and Load

Index	Buses closer to major generation	Buses closer to major load pockets
1	Niagara	Farragut
2	Clay	Dunwoodie
3	Marcy	Sprain Brook
4	Oakdale	Pleasant Valley
5	Gilboa	Millwood
6	Fraser	Goethals
7		Gowanus

Table 13: NYISO Wide-area Angle Pairs

Index	Pairs (From Generation To Load)
1	Niagara-Farragut
2	Marcy-Farragut
3	Gilboa-Farragut
4	Niagara-Sprain Brook

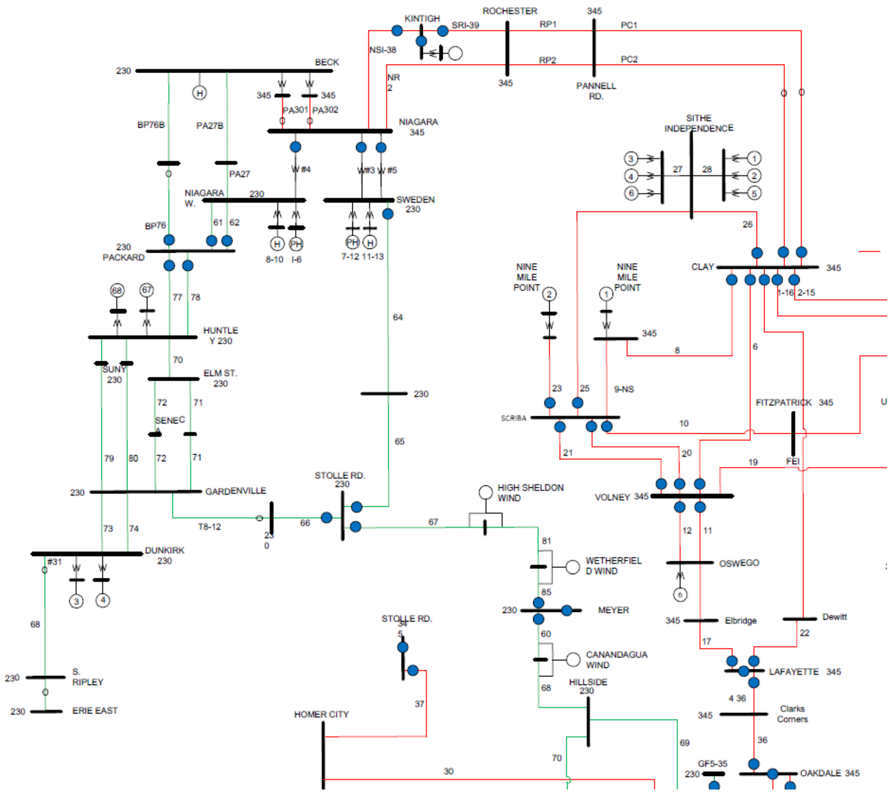


Figure 29: NYISO Generation-2 (NIAGARA/OAKDALE/CLAY)
Note: figure is portion of the NYCA 345-230 kV One-line diagram provided by NYISO.

Table 14: NYISO Segment Angle Pairs

Wide Area Pairs Index	Segment pair 1	Segment pair 2	Segment pair 3	Segment pair 4	Segment pair 5
1	Niagara - Clay	Clay - Marcy	Marcy - Pleasant Valley	Pleasant Valley - Sprain Brook	Sprain Brook - Farragut
2	Marcy - Leeds	Leeds - Millwood	Millwood - Sprain Brook	Sprain Brook - Farragut	
3	Gilboa - Leeds	Leeds - Pleasant Valley	Pleasant Valley - Sprain Brook	Sprain Brook - Farragut	

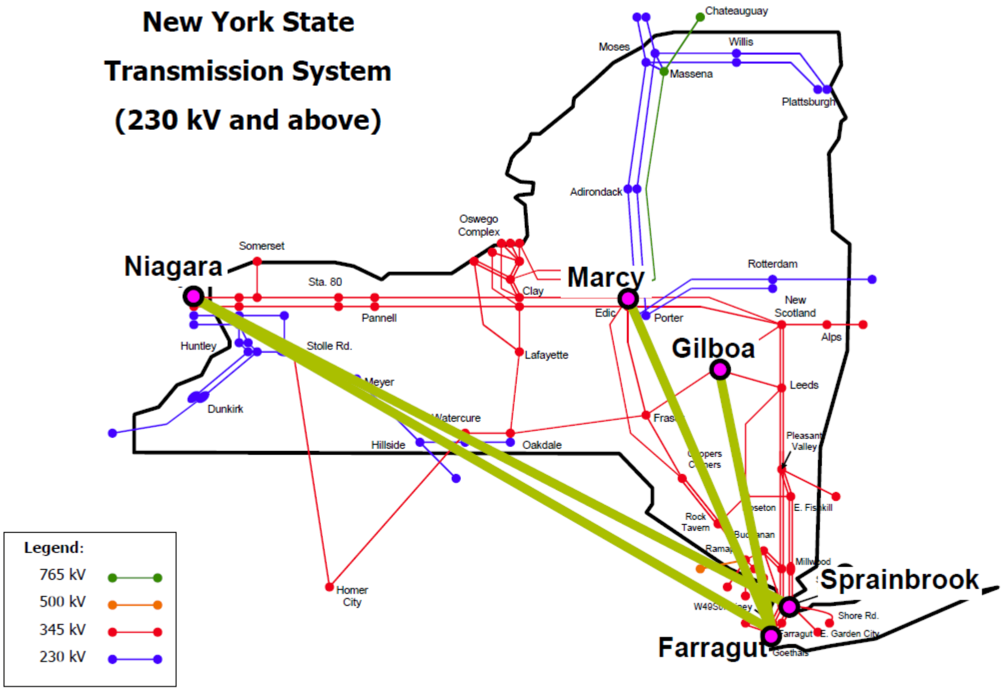


Figure 30: The NYISO Map of Wide Area Angle Pairs

7.3 Establish High and Low Range Values for NYISO Angle Pairs

Box-Whiskers charts and Time Duration plots were created for establishing the high/low range values for the selected angle pairs. Daily phase angle values are depicted as Box-and-Whisker plots show the daily phase angle values which is an effective way to display the large amount of data. The Time Duration plot is used to give a visual impression of the data distribution. It is an estimate of the probability distribution of a continuous variable. The plot easily identifies the angle difference range and its distribution for setting the high/low range values.

Figure 31 shows the Box-Whisker plot of Niagara-Farragut angle difference in two plots, each having 100 days in 2010 and 2011. Each box represents daily angle difference of Niagara-Farragut. Figure 32 shows Time Duration plot of angle difference of Niagara-Farragut. The complete box-whisker plot and time duration curve for selected angle pairs in NYISO area are provided in AppendixA.5.

The statistical analysis for all the selected angle pairs was tabulated in Table 15. The suggested monitoring range for each identified angle pair are based on the max/min values from each of the four months in 2010 and 2011. Since the data

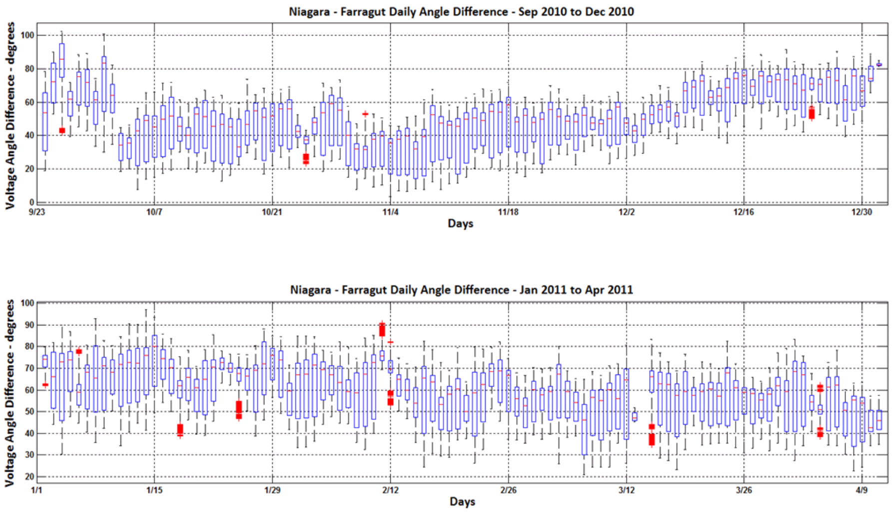


Figure 31: Box-whisker Plot of Niagara-Farragut Angle

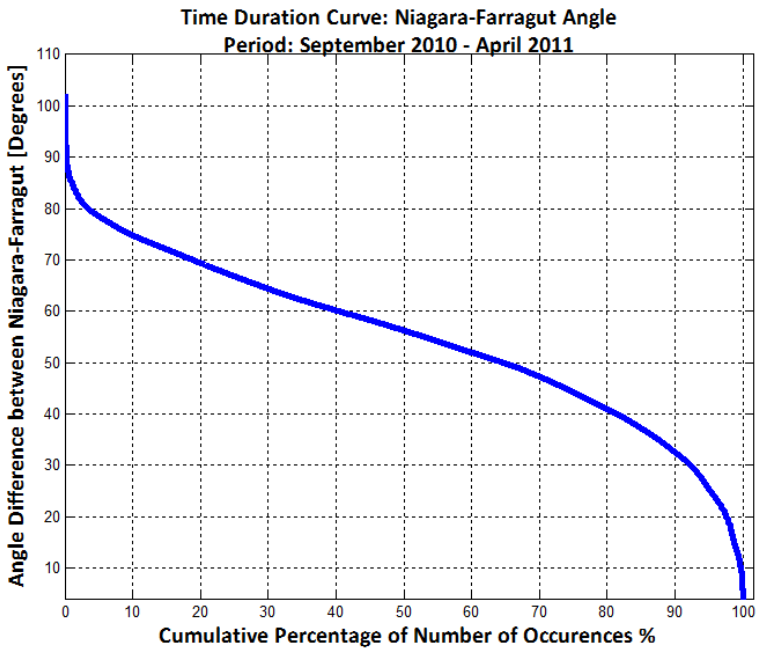


Figure 32: Time Duration Plot of Niagara-Farragut Angle

provided does not cover an entire year, the values suggested do not have a high confidence level.

The segment angle pairs are divided into four zones between Niagara and Farragut:

Zone 1 includes region between Niagara and Clay.

Zone 2 includes region between Clay and Leeds.

Zone 3 includes region between Gilboa and Pleasant Valley.

Zone 4 includes region between Millwood and Farragut.

The monitoring ranges are suggested for the above segment angle pairs grouped by area zones which also can be found in Table 15.

Table 15: Proposed High/Low Values for the Interested Angle Pairs Monitoring in NYISO footprint

Angle Pair	Angle	Sep 2010 to Dec 2010		Jan 2011 to Apr 2011		Monitoring	
Type	Pair	Min	Max	Min	Max	Low	High
Wide Area	Niagara - Farragut	4	102	21	97	4	102
	Marcy - Farragut	7	63	16	60	7	63
	Gilboa - Farragut	4	45	5	36	4	45
	Niagara - Sprainbrook	4	90	20	96	4	96
Segment Area Zone 1	Niagara - Clay	7	63	16	60	7	63
Segment Area Zone 2	Clay - Marcy	72	26	83	30	72	30
	Marcy - Leeds	41	18	50	21	41	21
	Leeds - Millwood	40	16	42	19	40	19
Segment Area Zone 3	Marcy - Pleasant Valley	0	0	0	0	0	0
	Gilboa - Leeds	20	2	20	5	20	5
	Leeds - Pleasant Valley	27	9	31	10	27	10
Segment Area Zone 4	Millwood - Sprain Brook	0	0	0	0	0	0
	Pleasant Valley - Sprain Brook	20	2	20	5	20	5
	Sprain Brook - Farragut	27	9	31	10	27	10

The proposed high value for angle pair monitor is established at the 0.5% of the cumulative percentage of the observations
The proposed low value for angle pair monitor is established at the 99.5% of the cumulative percentage of the observations

7.4 Conclusions and Observations

This section presents the statistical analysis of the SE data provided by NY ISO. The provided covers 8 months period from September 2010 to April 2011, but not the summer of 2010 or 2011. There are total of 5 wide angle pair and 7 segment angle pairs recommended for monitoring based on the analysis of this data. Reference values and range have for each of the angle pairs been suggested, however would need to be modified with inclusion of data for a summer. The results of the analysis were provided to NY ISO in the report submitted on March 13, 2013. No outlier analysis could be conducted in absence of SE data.

8 DATA ANALYSIS FOR ISONE FOOTPRINT[1]

8.1 Data Extraction and Analysis Procedure

Figure 33 below illustrates the flow of data as well as the process that are involved in performing the baselining analysis for the ISONE area.

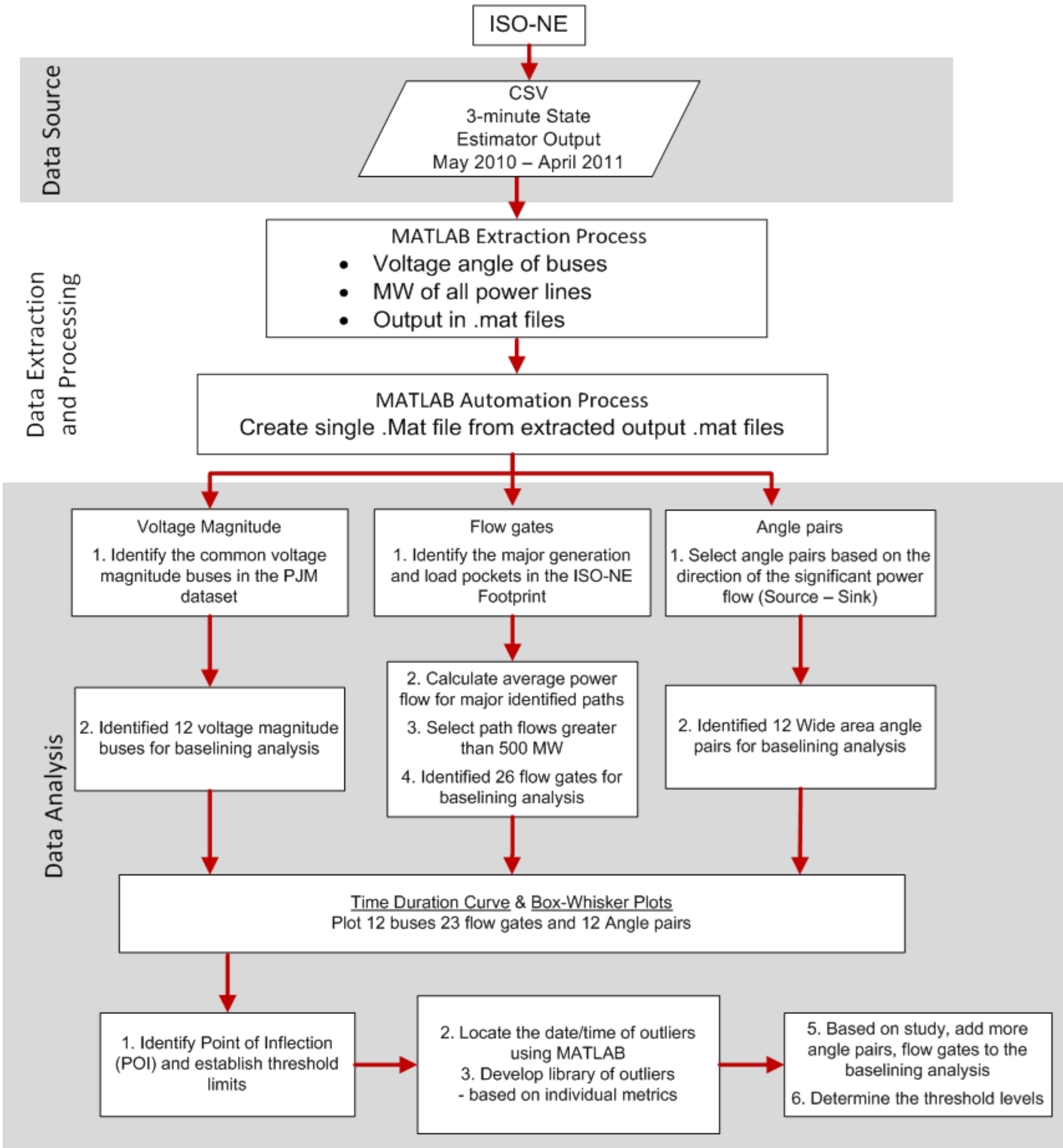


Figure 33: Flowchart of Analysis Procedure for ISONE

[1] ISONE Baselining Analysis Interim Report was submitted on March 25, 2013

The 3-minute state estimator snapshots were given by ISO-NE in *.CSV file format. There is no voltage magnitude signals provided by ISO-NE. Matlab was used as an automation tool to extract the data for calculation of statistical result and plotting distribution charts to identify the outliers, and establishing high/low monitoring. Matlab codes in Figure 26 read CSV files and save the dataset into a single angle and power flow *.Mat files.

8.2 Angle Pairs Selection

For purposes of statistical analysis, angle pairs and power paths are identified based on the key stations, load centers, transmission interfaces, and existing/planned Phasor Measurement Unit (PMU) locations. Table 16 shows the list of major generation in the ISO-NE region which was obtained from the ISO-NE website for baselining purposes. Table 17 presents the list of major generations and load grouped by states.

Table 16: ISONE Major Generation

Report As of March 2012	Winter Season (MW)	Summer Season (MW)
BRAYTON PT 3	638.000	612.000
CANAL 1	555.815	547.059
CANAL 2	547.000	545.125
MILLSTONE POINT 2	879.305	875.260
MILLSTONE POINT 3	1235.001	1225.000
MYSTIC 7	559.775	560.469
PILGRIM NUCLEAR POWER STATION	684.746	677.284
SEABROOK	1246.650	1246.225
VT YANKEE NUCLEAR PWR STATION	628.000	604.250
YARMOUTH 4	605.875	603.225
BRIDGEPORT ENERGY 1	533.678	454.434
MAINE INDEPENDENCE STATION	538.275	488.275
MYSTIC 8	841.564	703.324
MYSTIC 9	843.950	695.190
GRANITE RIDGE ENERGY	799.322	661.322
RISEP	575.000	536.419
NAEA NEWINGTON ENERGY& LLC	559.523	506.244
FORE RIVER-1	836.632	688.297
KLEEN ENERGY	620.000	620.000

Source: ISO-NE Website

The ISONE wide area angle pairs are shown in Table 18. Figure 34 gives the geographical overview of wide area angle pairs in the ISO-NE region.

Table 17: ISONE Major Generation and Major Load Grouped by State

ISONE Region	
Major Generation	**Major Load**
Mass	
Pilgrim	Sandy Pond
Canal	Ludlow
Brayton Point	Millbury
North field	Berkshire
CT	
Millstone Point	Manchester
	Long Mountain
	Norwalk
VT	
Vermont Yankee	Coolidge
Comerford (HVDC)	West Rutland
	New Haven
NH	
SeaBrook	Scobie
	Deerfield
Maine	
Maine Yankee	Orrington
	Maxcy's
	Buxton

Source: ISO-NE Website

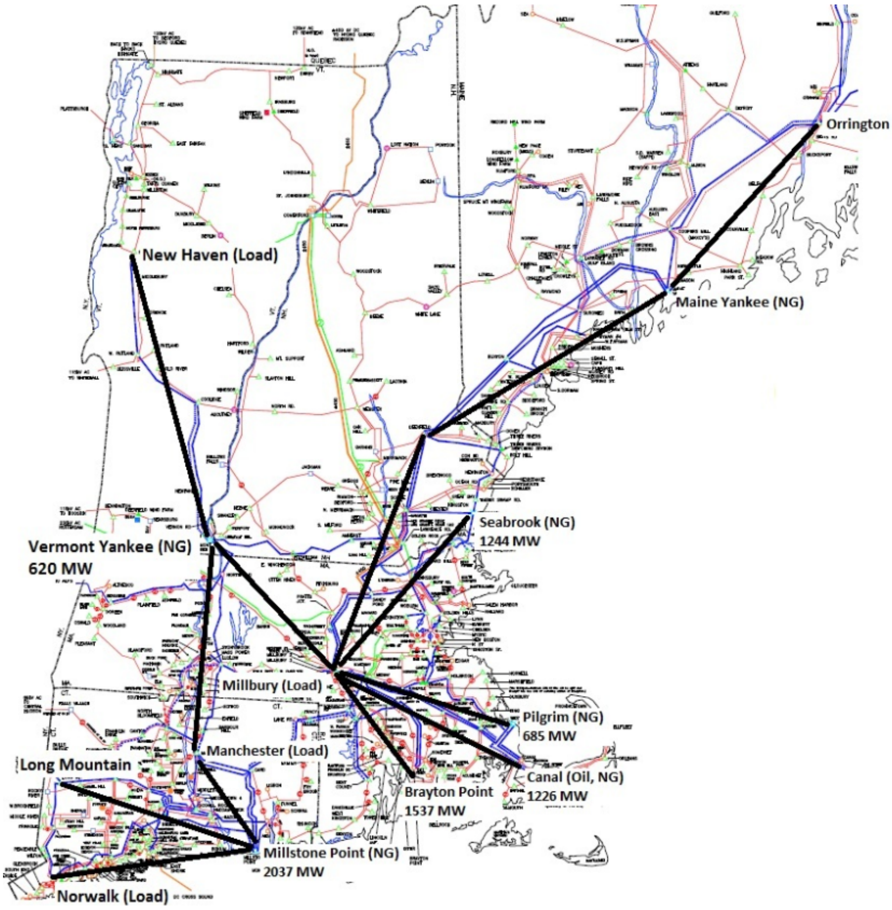


Figure 34: Geographical Overview of Wide Area Angle Pairs in the ISO-NE Region

Table 18: ISONE Wide Area Angle Pairs

Wide Area Angle Pairs		
Index	Source	Sink
1	Seabrook	Millbury
2	Millstone Point	Norwalk
3	Millstone Point	Manchester
4	Millstone Point	Long Mountain
5	Vermont Yankee	Manchester
6	Vermont Yankee	New Haven
7	Vermont Yankee	Millbury
8	Maine Yankee	Millbury
9	Orrington	Millbury
10	Canal	Millbury
11	Pilgrim	Millbury
12	Brayton Point	Millbury

8.3 Establish High and Low Range Values for ISONE Angle Pairs

To establish the monitoring range for the selected angle pairs, Box-Whiskers charts and Time Duration plots were created. Daily phase angle values are depicted as Box-and-Whisker plots in order to display the large amount of data in an effective way. Time duration plot is an estimate of the probability distribution of a continuous Variable and can help in identifying the proportion of data points that fall into each of several categories and help in establishing the ranges.

Figure 36 and Figure 35 show the Seabrook-Millbury angle pair Time Duration curve and Box Whisker plot respectively. The Time Duration plot gives a visual impression of the distribution of the angle value. The monitoring high/low values are identified and established around 1% and 99% percentile after removing the abnormal data. The 1% and 99% percentile criteria are established because of the data sampling rate, availability and observation.

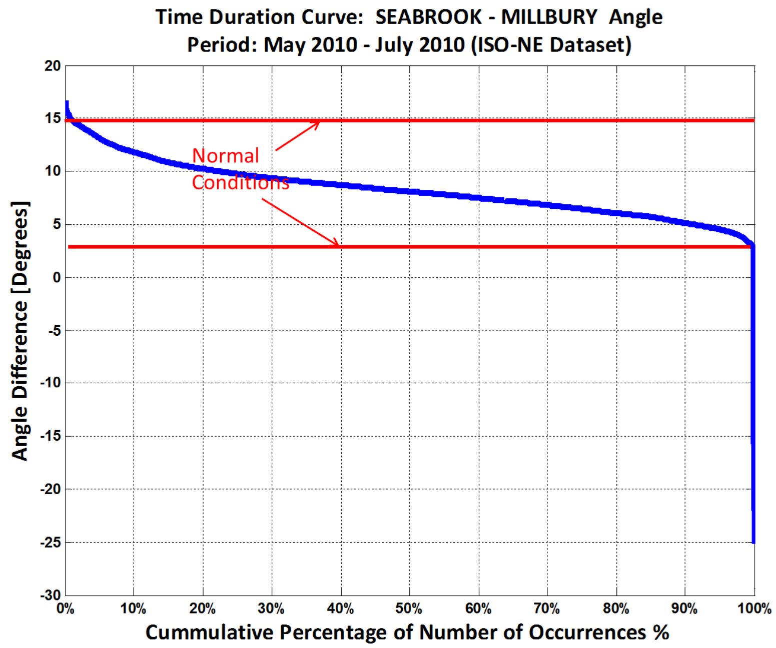


Figure 35: Time Duration plot of Seabrook-Millbury Wide Area Angle Pair

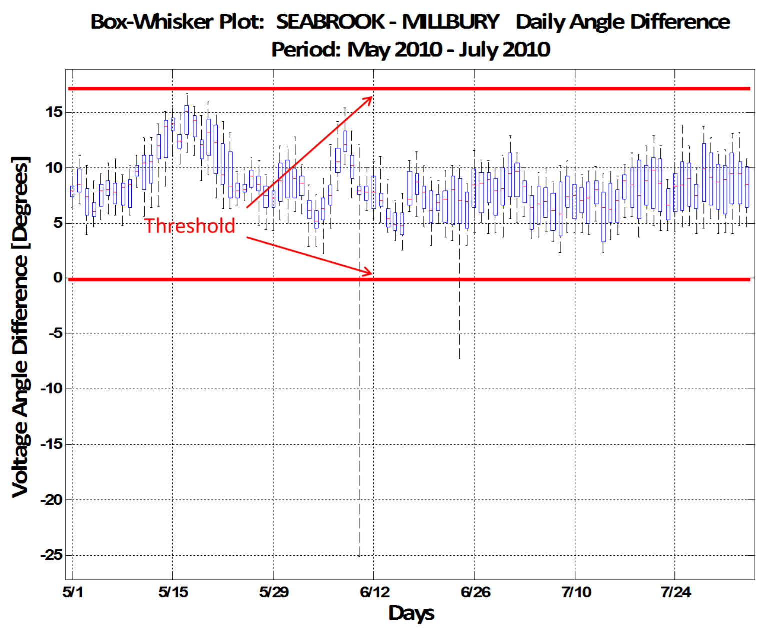


Figure 36: Box Whisker Plot of Seabrook-Millbury Wide Area Angle Pair

Table 19: Proposed High/Low Values for the Interested Angle Pairs Monitoring in ISONE footprint(Summer 2010, Winter 2010-2011 and Entire Data)

Date Range	Wide Area Angle Pairs	Low Value(deg)	High Value (deg)
Summer 2010 May 2010 to July 2010	Seabrook - Millbury	0	17
	Millstone Point - Norwalk	2	18
	Millstone Point - Manchester	-1	6
	Millstone Point - Long Mountain	2	22
	Vermont Yankee - Manchester	-6	50
	Vermont Yankee - New Haven	-5	40
	Vermont Yankee - Millbury	-10	40
	Maine Yankee - Millbury	-10	25
	Orrington - Millbury	-10	40
	Canal - Millbury	-5	5
	Pilgrim - Millbury	-5	5
	Brayton Point - Millbury	-5	7
Winter 2010-2011 Sep 2010 to Apr 2011	Seabrook - Millbury	0	20
	Millstone Point - Norwalk	0	30
	Millstone Point - Manchester	0	10
	Millstone Point - Long Mountain	0	25
	Vermont Yankee - Manchester	-5	25
	Vermont Yankee - New Haven	-5	20
	Vermont Yankee - Millbury	-5	15
	Maine Yankee - Millbury	-20	30
	Orrington - Millbury	-30	50
	Canal - Millbury	-10	5
	Pilgrim - Millbury	-5	10
	Brayton Point - Millbury	-5	10
Entire Data All Seasons	Seabrook - Millbury	0	20
	Millstone Point - Norwalk	0	30
	Millstone Point - Manchester	-1	10
	Millstone Point - Long Mountain	0	25
	Vermont Yankee - Manchester	-6	50
	Vermont Yankee - New Haven	-5	40
	Vermont Yankee - Millbury	-10	40
	Maine Yankee - Millbury	-20	30
	Orrington - Millbury	-30	50
	Canal - Millbury	-10	5
	Pilgrim - Millbury	-5	10
	Brayton Point - Millbury	-5	10

The proposed high value for angle pair monitor is established at the 1% of the cumulative percentage of the observations
The proposed low value for angle pair monitor is established at the 99% of the cumulative percentage of the observations

caption, can be commented out if no caption is required

8.4 Conclusions and Observations

This section presents the statistical analysis conducted on the SE data provided by ISO NE. extracted from the SE. The data included voltage , voltage angles and power flows on selected busses. Based on this data a total of 12 angle pairs were selected. The data covers about 11 months of data with about 90 percent availability. Based on this analysis, angle pair ranges have been analyzed and presented to ISO NE. A report was submitted on March 25, 2013. It is recommended that analysis be done again with complete one year data to increase confidence level in the analysis results.

Next, a study will be carried out by focusing on the region covering the four ISOs as a whole.

9 WIDE AREA ANGLE PAIRS ACROSS ISOS BASE-LINING ANALYSIS

In previous sections, the statistical analysis has been presented for each of the individual ISO data. This information generated the angle pairs and established its range but within the ISO. One of the advantages of the synchro-phasor technology is its capability to monitor angle differences across wide area that is across ISOs and such angle pairs and angle pair range values that may be monitored in future with synchro-phasor data being available. Te two options available at this time were 1) either to wait till the synchro-phasor system data is available 2) try to combine or stitch the available data from different ISOs. The difficulty of the second option was however, fully understood, while undertaking this approach.

The work involved in selection of wide area angle pairs across ISO regions was identified as follows:

- Select angle pairs for inter ISO regions
- Select time period for analysis when data is available from all four ISOs
- Develop method to combine data from four ISOs
- Conduct statistical analysis of selected wide-area angle pairs
- Examine the correlation between angle differences and MW flows(and Voltages)

9.1 Angle Pairs Selection

The wide-area angle pairs are selected based on the recommendations of the Technical Advisory Group (TAG). Member of the each ISO participating in TAG was requested to suggest the name of the angle pair that they would like to be included in analysis. The selection, in general, was based on where the major power transfers occurred or what may be most useful in operation and where the PMUs are installed or are planned to be installed. Table 20 shows the list of final recommended angle pairs from TAG. The table also gives the reason of the selection. Figure 37 gives the geographical overview of wide area angle pairs covering four ISOs.

Table 20: Wide Area Angle Pairs Covering Four ISOs

Index	From bus	To bus	Reason
1	Raun	Sub 91	IA Wind Transfers
2	Goodings	Arcadian	Wi-Chi Transfers
3	Goodings	Palisades	Chi-MI Transfers
4	Labadie	Hanna	West to East Transfers
5	Labadie	Cumberland	St Louis South Transfers
6	Jacksons Ferry	Cumberland	TVA to PJM (Southwest) Transfers
7	Canton Centr.	Monroe	SE MI Transfers
8	Alburtis	Canton Centr.	West to East Transfers (Lake Erie Loop)
9	Alburtis	Jacksons Ferry	Southwest to East Transfers
10	Alburtis	Ramapo	PJM to NYISO
11	Niagara	Monroe	NYISO to MISO
12	Niagara	Ramapo	West to Southeast Transfers
13	Ramapo	Millbury	NYISO to ISONE
14	Raun	Ramapo	MISO to NYISO
15	Arcadian	Ramapo	MISO to NYISO
16	Goodings	Monroe	Close the loop
17	Goodings	Hanna	Close the loop
18	Hanna	Monroe	Close the loop
19	Hanna	Canton Centr.	Close the loop
20	Palisades	Monroe	Close the loop
21	Raun	Millbury	MISO to ISONE
22	Arcadian	Millbury	MISO to ISONE

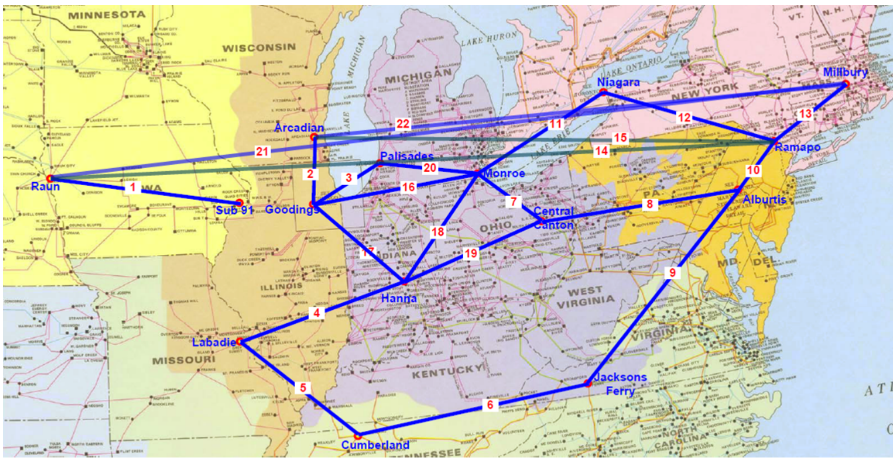


Figure 37: Geographical Overview of Wide Area Angle Pairs Covering Four ISOs

9.2 Methods to Combine Data from ISOs

9.2.1 Challenges for Data Combining

In order to combine data from four ISOs, the following requirements have to be met.

- Common Time Period
- Common Sampling Rate
- Common Time Stamp

According the Figure 2, there is only one month common time period in which four ISOs have complete data without missing data, March 2011. It is found the data from different ISO has the different sampling rate and different time stamp as shown in Figure 38.

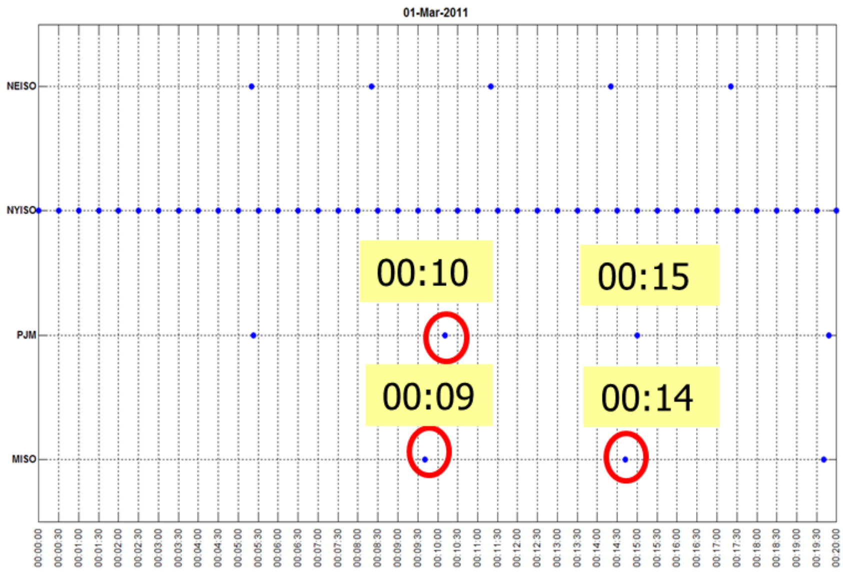


Figure 38: Geographical Overview of Wide Area Angle Pairs Covering Four ISOs

While analyzing data, it is observed that there are different power flow solutions even for same bus but from different ISO files. Figure 39 shows the comparison of an identified common angle pair Gilboa-Farragut in PJM, MISO and NYISO datasets in first 5 hours of March 1st of 2011. The comparison plot shows the NYISO and PJM data is very close. The MISO data is away from the other two datasets. Figure 40 shows another example of comparison. It shows the comparison of an identified common angle pair Pilgrim-Sandy pond 345kV in PJM and ISO-NE datasets in first 5 hours of March 1st of 2011. The comparison plot shows the ISO-NE and PJM data is not very close, but has the same signature. The likely cause of the difference could be ISO-NE model may not be updated in PJM power flow models. It is also seen that the bus angle reference buses in four ISOs are different. Thus, in order to combine data from different ISOs, a common offset needs to be established between two different ISOs.

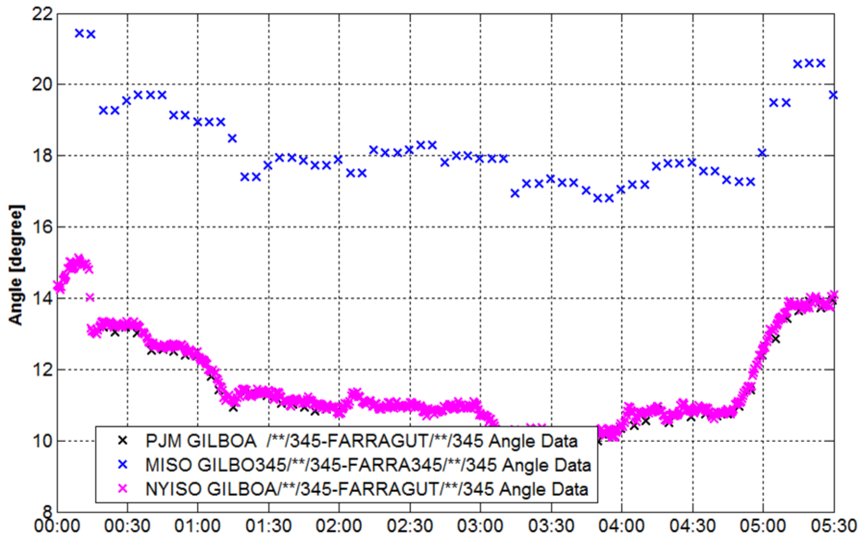


Figure 39: Comparison of PJM, MISO and NYISO Angle Data for Gilboa-Farragut 345kV (NYISO Footprint)

9.2.2 Data Combining Method

In order to overcome the challenges, the following Figure 41 shows the procedures to be followed in order to analyze angle pairs across ISOs.

After the angle pairs are selected, there is a procedure to evaluate the bus data availability in each ISO file. If both buses(from and to bus) are available in one single ISO file, there is no need to apply stitching method. If either from- or to bus can't be found one single ISO file, it means the stitching method has to be used in order to combine data from two ISO files.

The following Table 21 shows the data availability of the selected angle pair buses in different ISO files. In the table, $\surd$ means both from and to bus can be found in the same ISO file. Angle pair 13, 21 and 22, either the to- or from bus data is not found in the same ISO file, will need stitching method to combine the data from different ISOs. Table 21 also provides the data comparison between PJM

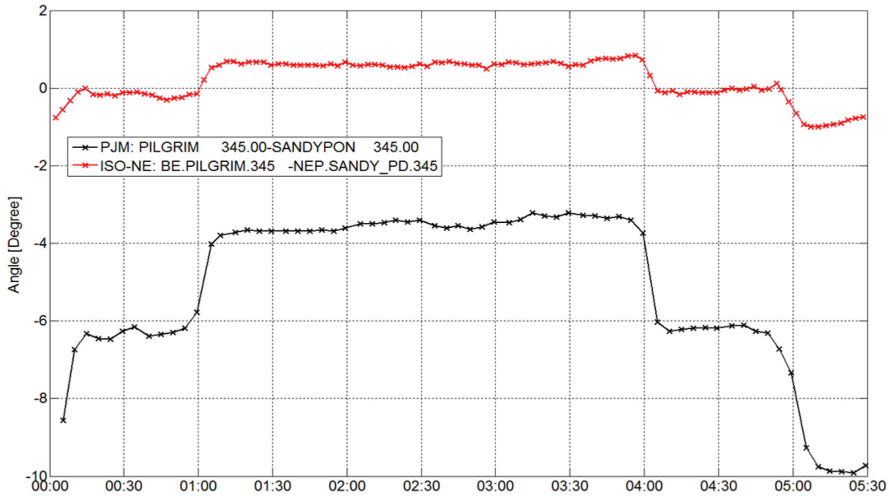


Figure 40: Comparison of PJM and ISO-NE Data for Pilgrim-Sandy Pond 345kV (ISO-NE Footprint)

and MISO and the data comparison between PJM and NYISO. It shows there is the difference between the ISOs' data even for the same angle pairs. For example, angle pair 17 (Goodings 345kV-Hanna 345kV) shows the difference between PJM and MISO has 0 median with 1.6 standard deviation.

Table 21: Bus Angle Pairs Data Availability and Comparison

Index	From bus	To bus	PJM Available	MISO Available	NYISO Available	ISONE Available	PJM-MISO Data Difference Median	PJM-MISO Data Difference STD	PJM-NYISO Data Difference Median	PJM-NYISO Data Difference STD
1	Raun 345kV	Sub 91 345kV	√	√			6	5.5		
2	Goodings 345kV	Arcadian 345kV	√	√			-1.5	2.1		
3	Goodings 345kV	Palisades 345kV	√	√			0.2	2.1		
4	Labadie 345kV	Hanna 345kV	√	√			2.9	2.6		
5	Labadie 345kV	Cumberland 500kV	√	√			2.9	2.1		
6	Jacksons Ferry 765kV	Cumberland 500kV	√	√			-0.5	2.1		
7	Canton Centr. 345kV	Monroe 345kV	√	√			0	1.7		
8	Alburtis 500kV	Canton Centr. 345kV	√	√			-0.9	2.5		
9	Alburtis 500kV	Jacksons Ferry 765kV	√	√			-0.6	3.3		
10	Alburtis 500kV	Ramapo 500kV	√	Alburtis						
11	Niagara 345kV	Monroe 345kV	√	√			0.7	3		
12	Niagara 345kV	Ramapo 500kV	√	Niagara	√				0.5	0.6
13	Ramapo 500kV	Millbury 345kV	Ramapo		Ramapo	Millbury				
14	Raun 345kV	Ramapo 500kV	√	Raun	Ramapo					
15	Arcadian 345kV	Ramapo 500kV	√	Arcadian	Ramapo					
16	Goodings 345kV	Monroe 345kV	√	√			0.4	3		
17	Goodings 345kV	Hanna 345kV	√	√			0	1.6		
18	Hanna 345kV	Monroe 345kV	√	√			0.4	2.3		
19	Hanna 345kV	Canton Centr. 345kV	√	√			0.4	1.8		
20	Palisades 345kV	Monroe 345kV	√	√			0.2	1.5		
21	Raun 345kV	Millbury 345kV	Raun	Raun		Millbury				
22	Arcadian 345kV	Millbury 345kV	Arcadian	Arcadian		Millbury				

In summary, for the angle pairs which both from and to bus can be found in

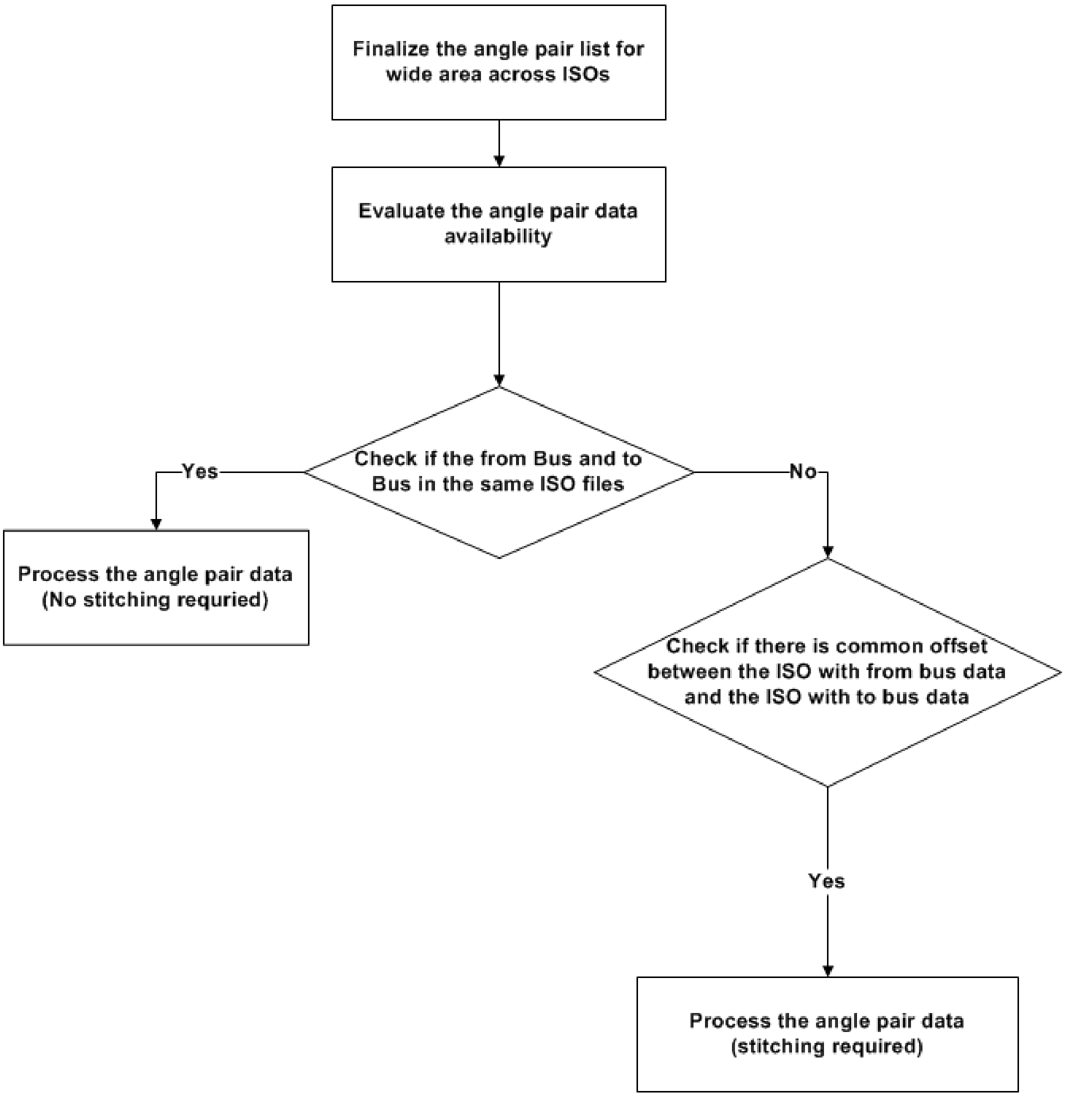


Figure 41: Flowchart of Analysis Data for Angle Pair across ISOs

the same ISO file, the analysis is pretty straightforward. There is no data stitching involved. For the angle pairs 13, 21 and 22, the data from different ISOs has to be used for angle calculation. With different time stamp and different sampling rate in different ISO files, it is decided a linear interpolation has to be used which will inevitably introduce the calculation error.

It is also known that the bus reference is different in different ISO file. Therefore, the common offset has to be established between two different ISOs before we do the angle calculation.

Table 22 shows the common buses found in both PJM and ISONE. The bus angle differences between these two ISOs are investigated for these common buses. The median and standard deviation of the difference is provided in the table. Since variability of the median is high, it can be concluded there is no common offset between PJM and ISONE data. Similar Tables 23, 24, 25 and 26 are presented. There are common offsets in ISONE-NYISO, PJM-NYISO and MISO-NYISO except Ramapo 345kV bus and Sandypond 345kV bus. But there is no common offset found in ISONE-PJM and ISONE-MISO.

Table 22: Common Buses Found in ISO-NE and PJM Files

Common Buses Found in ISO-NE and PJM files				
Bus Name	ISO-NE	PJM	Mean of Offset	STD of Offset
LAWRENC2 345kV	O	√	-54	14
LONGMOUN 345kV	O	√	3	13
LUDLOW 345kV	O	√	-37	15
MASON 345kV	O	√	-89	17
MIDDLETN 345kV	O	√	-71	12
MILSTONE 345kV	O	√	5	14
MYSTIC 345kV	O	√	20	15
PILGRIM 345kV	O	√	17	15
SANDY_PD 345kV	O	√	9	13

O–Bus in its owner ISO files √–Bus data is found in this ISO files

Table 23: Common Buses Found in ISO-NE and MISO Files

Common Buses Found in ISO-NE and MISO Files					
Bus Name	ISO-NE	MISO	Mean of Offset	STD of Offset	
LUDLOW 345kV	O		√	-40	14
MASON 345kV	O		√	-94	15
MIDDLETN 345kV	O		√	7	12

O–Bus in its owner ISO files √–Bus data is found in this ISO files

For the angle pair 13 listed in Table 21, there is only one offset required which is the offset between NYISO-ISONE. For angle pair 21 and 22, two common offsets are required, offset between PJM-NYISO and NYISO-ISONE.

Table 24: Common Buses Found in ISO-NE and NYISO Files

Common Buses Found in ISO-NE and NYISO Files				
Bus Name	ISO-NE	NYISO	Mean of Offset	STD of Offset
MILSTONE 345kV	O	√	-12	15
SANDY_PD 345kV	O	√	-11	15

O–Bus in its owner ISO files √–Bus data is found in this ISO files

Table 25: Common Buses Found in PJM and NYISO Files

Common Buses Found in NYISO and PJM Files				
Bus Name	NYISO	PJM	Mean of Offset	STD of Offset
Keystone 500kV	√	O	16	15
Kintigh 345kV	O	√	16	15
Ladentow 345kV	O	√	15	15
Leeds 345kV	O	√	15	15
Limerick 345kV	O	√	15	15
Marcy 345kV	O	√	16	15
Millston 345kV	O	√	17	15
Millwood 345kV	O	√	14	15
Niagar 345kV	O	√	16	15
Oakdale 345kV	O	√	16	15
Rainey 345kV	O	√	16	15
Ramapo 500kV	O	√	15	15
Ramapo 345kV	O	√	5	15
Rocheste 345kV	O	√	16	15
Roseton 345kV	O	√	15	15
Sandypon 345kV	√	√	20	15
Sprainbrook 345kV	O	√	15	15

O–Bus in its owner ISO files √–Bus data is found in this ISO files

Table 26: Common Buses Found in MISO and NYISO Files

Common Buses Found in NYISO and PJM Files				
Bus Name	NYISO	MISO	Mean Value of Offset	STD of Offset
Keystone 500kV	√	√	12	15
Kintigh 345kV	O	√	12	15
Ladentow 345kV	O	√	13	15
Leeds 345kV	O	√	13	15
Limerick 345kV	O	√	12	15
Marcy 345kV	O	√	11	15
Niagar 345kV	O	√	12	15
Oakdale 345kV	O	√	11	15
Rainey 345kV	O	√	14	15
Ramapo 345kV	O	√	3	16
Rocheste 345kV	O	√	11	15
Roseton 345kV	O	√	13	15
Sprainbrook 345kV	O	√	14	16

O–Bus in its owner ISO files √–Bus data is found in this ISO files

Figure 42 shows an example of the stitching method with an application of one offset. This example shows how to apply one offset between NYISO-ISONE to calculate the angle difference between Ramapo and Millbury, by using Ramapo value in NYISO file and Millbury in ISONE file. The red line is the common offset found between NYISO-ISONE.

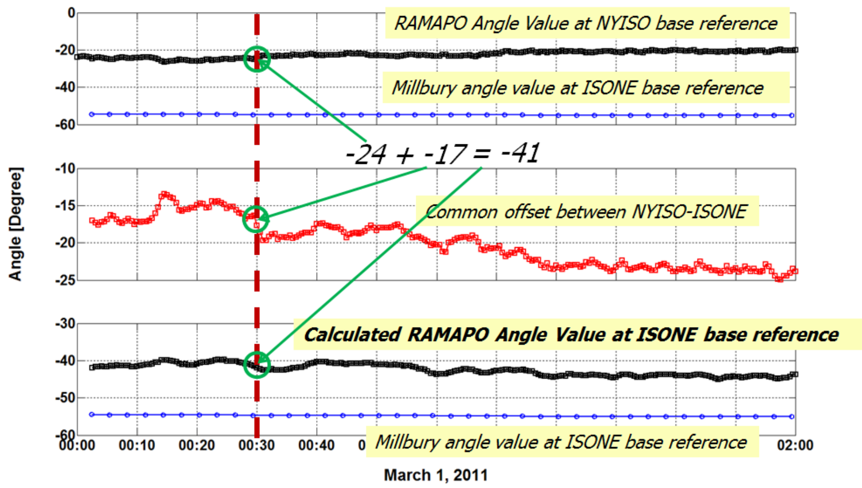


Figure 42: Example of Stitching Method with Applying One Offset

Figure 43 shows an example of the stitching method with an application of two offsets. The red lines are the common offset found in PJM-NYISO and the common offset found in NYISO-ISONE. The original values are Arcadia angle value at PJM base reference and Millbury angle value at ISONE base reference. After applying two offsets, the Arcadia angle value at ISONE base reference can be calculated. Therefore, the angle difference between Arcadia and Millbury can be compared.

The stitching method with one offset is validated in Figure 44 for the angle pair ARCADIA-RAMAPO. One offset of PJM-NYIS is applied. The calculated Ramapo angle value at PJM base reference (blue line) is pretty close to the Ramapo angle value from PJM data file (pink line).

9.3 Establish High and Low Values for Angle Pairs across ISOs

To establish the high/low monitoring values for the selected angle pairs, Box-Whiskers charts and Time Duration plots were created. From the Time Duration plots, the high and low values are established at 0.5% and 99.5% of time by using

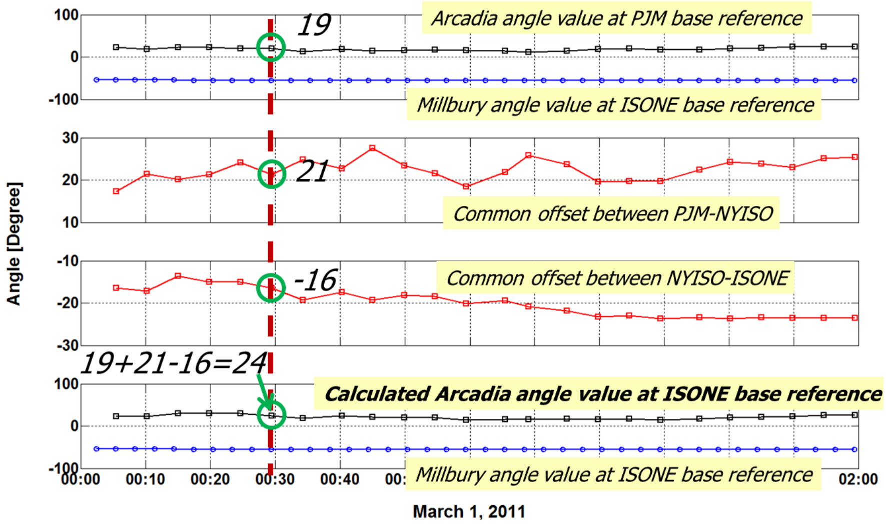


Figure 43: Example of Stitching Method with Applying Two Offsets

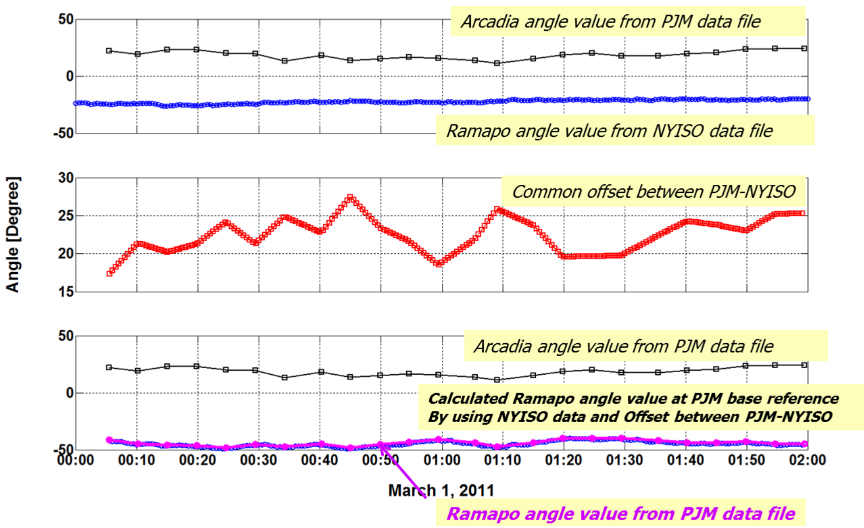


Figure 44: Validation Stitching Methodology with One Offset

one month of common time period of data. Figure 45 and 46 show an example of Time Duration plots and Box-Whiskers charts for angle pair between Ramapo 500kV-Millbury 345kV.

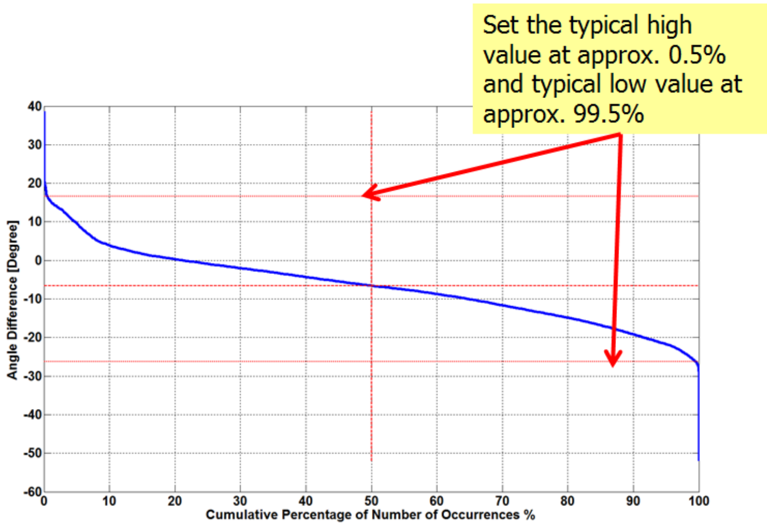


Figure 45: Time Duration Plot for Establishing High and Low Values for Monitoring Ramapo 500kV-Millbury 345kV

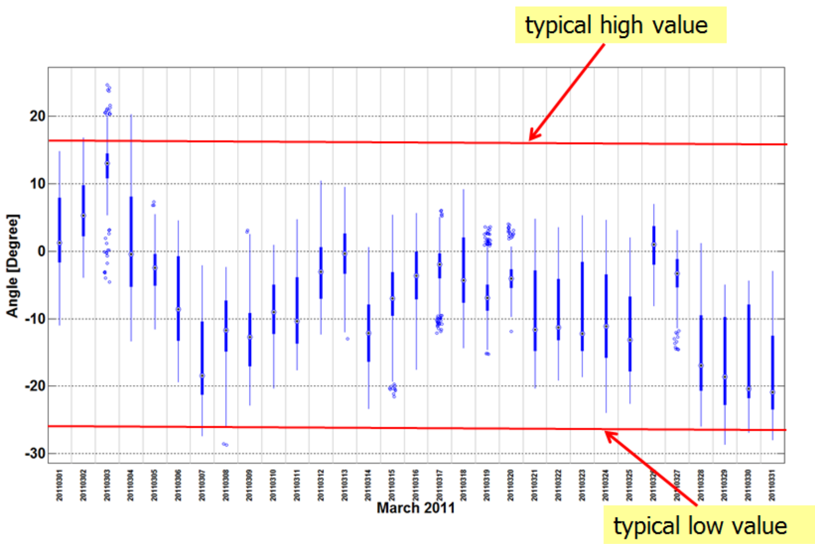


Figure 46: Box-Whisker Chart for Ramapo 500kV-Millbury 345kV

The high and low monitoring values are established and shown in following Table 27 and 28 for all the interested angle pairs. Table 27 lists all the angle pairs high and low monitoring values established based on the data from different ISO. The recommended values use the high/low values established based on its owner ISO data.

Table 27: Proposed High/Low Values for Wide Area Bus Angle Pairs without Stitching Method

Index	From bus	To bus	PJM		MISO		NYISO		Proposed	
			Low	High	Low	High	Low	High	Low	High
1	Raun 345kV	Sub 91 345kV	-4.1	38.7	-13.3	47.7			-13.3	47.7
2	Goodings 345kV	Arcadian 345kV	-8.1	13.6	-9.6	11.4			-8.1	13.6
3	Goodings 345kV	Palisades 345kV	6.5	29.3	6.6	29.3			6.5	29.3
4	Labadie 345kV	Hanna 345kV	20	53.9	22.8	56.7			22.8	56.7
5	Labadie 345kV	Cumberland 500kV	5.7	32.7	8.9	34.9			8.9	34.9
6	Jacksons Ferry 765kV	Cumberland 500kV	-47	-18.7	-47.5	-19.2			-47	-18.7
7	Canton Centr. 345kV	Monroe 345kV	-10.2	11.6	-10.4	11.6			-10.4	11.6
8	Alburtis 500kV	Canton Centr. 345kV	-45.8	-10.4	-46.1	-10			-45.8	-10.4
9	Alburtis 500kV	Jacksons Ferry 765kV	-60.4	-12.1	-61.3	-13			-60.4	-12.1
10	Alburtis 500kV	Ramapo 500kV	2.3	18					2.3	18
11	Niagara 345kV	Monroe 345kV	-28.4	12.1	-26.1	12.1			-26.1	12.1
12	Niagara 345kV	Ramapo 500kV	8.9	56.6			9.4	57.2	9.4	57.2
14	Raun 345kV	Ramapo 500kV	66.4	153.8					66.4	153.8
15	Arcadian 345kV	Ramapo 500kV	38.9	108.9					38.9	108.9
16	Goodings 345kV	Monroe 345kV	21.6	53.7	22	54.4			22	54.4
17	Goodings 345kV	Hanna 345kV	0.2	22.7	0.1	22.7			0.1	22.7
18	Hanna 345kV	Monroe 345kV	10	44.9	10.5	45.7			10.5	45.7
19	Hanna 345kV	Canton Centr. 345kV	12.2	41.7	12.6	41.9			12.6	41.9
20	Palisades 345kV	Monroe 345kV	7.1	28.4	7.9	29			7.9	29

The proposed high value for angle pair monitor is established at the 0.5% of the cumulative percentage of the observations
The proposed low value for angle pair monitor is established at the 99.5% of the cumulative percentage of the observations

Table 28: Proposed High/Low Values for Wide Area Bus Angle Pairs with Stitching Method

Index	From bus	To bus	Low Value	High Value	Note
13	Ramapo 500kV	Millbury 345kV	-26.2	16.6	Apply one offset, NYISO-ISONE
21	Raun 345kV	Millbury 345kV	26.4	117.2	Apply two offsets, NYISO-ISONE and PJM-NYISO
22	Arcadian 345kV	Millbury 345kV	50.6	158.8	Apply two offsets, NYISO-ISONE and PJM-NYISO

There are additional on/off peak, and weekday type analyses are performed for these wide area angle pairs. The proposed high/low monitoring values for weekday type are provided in Tables 29 and 30. The high/low monitoring values for on-peak/ off-peak type are provided in Tables 31 and 32.

Table 29: Proposed High/Low Values for Wide Area Bus Angle Pairs without Stitching Method by Weekday Type

Index	From bus	To bus	PJM				MISO				NYISO				Proposed			
			WeekDay		WeekEnd		WeekDay		WeekEnd		WeekDay		WeekEnd		WeekDay		WeekEnd	
			Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1	Raun 345kV	Sub 91 345kV	-5	39.4	-0.5	32.8	-14.6	48.7	-1.6	39.3					-14.6	48.7	-1.6	39.3
2	Goodings 345kV	Arcadian 345kV	-8.3	14.7	-6.2	8.6	-9.7	12.7	-7.3	6.6					-8.3	14.7	-6.2	8.6
3	Goodings 345kV	Palisades 345kV	6.6	29.5	5.9	28.3	6.7	29.4	5.9	28.1					6.6	29.5	5.9	28.3
4	Labadie 345kV	Hanna 345kV	20.1	54.3	19.8	51.3	23.2	57.1	22.6	53.9					23.2	57.1	22.6	53.9
5	Labadie 345kV	Cumberland 500kV	5.8	33.1	5.6	31.8	9.3	35.2	8.6	34.5					9.3	35.2	8.6	34.5
6	Jacksons Ferry 765kV	Cumberland 500kV	-47.4	-23.9	-45.1	-15.6	-48.1	-24.2	-45.3	-15.9					-47.4	-23.9	-45.1	-15.6
7	Canton Centr. 345kV	Monroe 345kV	-9.3	11.9	-11.2	4	-9.3	12	-11.4	4					-9.3	12	-11.4	4
8	Alburtis 500kV	Canton Centr. 345kV	-46.1	-9.6	-43.5	-11.2	-46.3	-9.1	-44.4	-11.9					-46.1	-9.6	-43.5	-11.2
9	Alburtis 500kV	Jacksons Ferry 765kV	-60.7	-15.7	-59.4	-9.2	-61.3	-15.8	-60.3	-10.2					-60.7	-15.7	-59.4	-9.2
10	Alburtis 500kV	Ramapo 500kV	2.1	18.1	4.1	14									2.1	18.1	4.1	14
11	Niagara 345kV	Monroe 345kV	-28.9	12.6	-19.2	7.2	-26.8	12.4	-18.2	7.3					-26.8	12.4	-18.2	7.3
12	Niagara 345kV	Ramapo 500kV	8.6	57.4	11.9	51.9					9.1	58.2	12.2	52.6	9.1	58.2	12.2	52.6
14	Raun 345kV	Ramapo 500kV	64.7	151.9	68.3	155.1									64.7	151.9	68.3	155.1
15	Arcadian 345kV	Ramapo 500kV	37.9	109.2	47.5	107.8									37.9	109.2	47.5	107.8
16	Goodings 345kV	Monroe 345kV	21.9	53.6	20.5	53.7	22.3	54.5	20.4	53.9					22.3	54.5	20.4	53.9
17	Goodings 345kV	Hanna 345kV	0.1	21.5	6.5	23.2	0	21.6	6.6	23.1					0	21.6	6.6	23.1
18	Hanna 345kV	Monroe 345kV	12	45.2	9.1	36.6	12.5	46.1	9.6	36.8					12.5	46.1	9.6	36.8
19	Hanna 345kV	Canton Centr. 345kV	16.5	43.9	10.8	36.6	16.8	44.3	11	36.7					16.8	44.3	11	36.7
20	Palisades 345kV	Monroe 345kV	6.7	28.4	8.2	28.2	7.4	29.4	9	28.4					7.4	29.4	9	28.4

Table 30: Proposed High/Low Values for Wide Area Bus Angle Pairs with Stitching Method by Weekday Type

Index	From bus	To bus	Weekday		Weekend		Note
Index	From bus	To bus	Low	High	Low	High	
13	Ramapo 500kV	Millbury 345kV	-26.4	17.2	-17.3	8.2	Apply one offset, NYISO-ISONE
21	Raun 345kV	Millbury 345kV	24.5	118.8	45	105.3	Apply two offsets, NYISO-ISONE and PJM-NYISO
22	Arcadian 345kV	Millbury 345kV	48.9	159.7	64.9	149.1	Apply two offsets, NYISO-ISONE and PJM-NYISO

Table 31: Proposed High/Low Values for Wide Area Bus Angle Pairs without Stitching Method by On/Off Peak Type

Index	From bus	To bus	PJM				MISO				NYISO				Proposed			
			OnPeak		OffPeak		OnPeak		OffPeak		OnPeak		OffPeak		OnPeak		OffPeak	
			Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1	Raun 345kV	Sub 91 345kV	-5.5	39.5	2	32.6	-15.4	48.8	2.5	41.5					-15.4	48.8	2.5	41.5
2	Goodings 345kV	Arcadian 345kV	-6.3	14.9	-9.1	12.3	-7.6	12.8	-10.5	10.7					-6.3	14.9	-9.1	12.3
3	Goodings 345kV	Palisades 345kV	5.9	27.6	11.1	29.8	6	27.2	10.8	29.8					5.9	27.6	11.1	29.8
4	Labadie 345kV	Hanna 345kV	19.7	54.4	22.6	51.9	22.3	57.1	24.5	54.3					22.3	57.1	24.5	54.3
5	Labadie 345kV	Cumberland 500kV	5.1	33.1	9.6	32.3	8	35.4	11.2	34.5					8	35.4	11.2	34.5
6	Jacksons Ferry 765kV	Cumberland 500kV	-44.4	-17.5	-48.5	-21.2	-45	-17.7	-49.3	-21.4					-44.4	-17.5	-48.5	-21.2
7	Canton Centr. 345kV	Monroe 345kV	-10	11.9	-10.8	9.9	-9.9	12	-11.2	9.4					-9.9	12	-11.2	9.4
8	Alburtis 500kV	Canton Centr. 345kV	-46	-14	-43.9	-8.5	-46.2	-14.9	-44.5	-7.3					-46	-14	-43.9	-8.5
9	Alburtis 500kV	Jacksons Ferry 765kV	-61.1	-19.8	-54	-9.4	-62.1	-19.8	-57.1	-10.7					-61.1	-19.8	-54	-9.4
10	Alburtis 500kV	Ramapo 500kV	4.5	18.1	1.7	15.8									4.5	18.1	1.7	15.8
11	Niagara 345kV	Monroe 345kV	-19.3	12.6	-29.7	6.6	-18.2	12.2	-27.7	11.6					-18.2	12.2	-27.7	11.6
12	Niagara 345kV	Ramapo 500kV	20.6	57.6	7.9	43.8					20.9	58.5	8.2	44.1	20.9	58.5	8.2	44.1
14	Raun 345kV	Ramapo 500kV	64.3	154.7	72.2	152.6									64.3	154.7	72.2	152.6
15	Arcadian 345kV	Ramapo 500kV	39.6	109.6	37.8	101									39.6	109.6	37.8	101
16	Goodings 345kV	Monroe 345kV	20.9	54.2	23.4	52.8	21.3	54.8	23.7	53.3					21.3	54.8	23.7	53.3
17	Goodings 345kV	Hanna 345kV	0.2	21.4	1.6	23.3	0	21.3	1.6	23.2					0	21.3	1.6	23.2
18	Hanna 345kV	Monroe 345kV	9.8	45.1	12.3	44.2	10.1	46.1	12.8	44					10.1	46.1	12.8	44
19	Hanna 345kV	Canton Centr. 345kV	11.8	44.2	12.7	39.7	12.1	44.6	13	39.5					12.1	44.6	13	39.5
20	Palisades 345kV	Monroe 345kV	9.9	28.8	6	26.7	12	29.7	6.2	27.1					12	29.7	6.2	27.1

Table 32: Proposed High/Low Values for Wide Area Bus Angle Pairs with Stitching Method by On/Off Peak Type

Index	From bus	To bus	OnPeak		OffPeak		Note
Index	From bus	To bus	Low	High	Low	High	
13	Ramapo 500kV	Millbury 345kV	-26.6	16	-22	17.6	Apply one offset, NYISO-ISONE
21	Raun 345kV	Millbury 345kV	25	118.1	28.5	114.9	Apply two offsets, NYISO-ISONE and PJM-NYISO
22	Arcadian 345kV	Millbury 345kV	48.4	152.6	67.5	161.7	Apply two offsets, NYISO-ISONE and PJM-NYISO

9.4 Examination of Correlation between Angle Difference and MW Flows (and Voltage Magnitude)

In order to understand the relation between the phase angle difference and the bus voltage (and MW flow), the correlation between them is examined. In this section, two examples are presented. One is in PJM area and the other is in MISO area.

The following Figure 47 shows the central transfer interface of PJM with three critical transmission lines (KEYSTONE-JUNIATA, CONEMAUG-JUNIATA AND CONASON-PEACHBOT). The monitored bus angle pair is the Canton Central-Alburtis which also can be found in the figure.

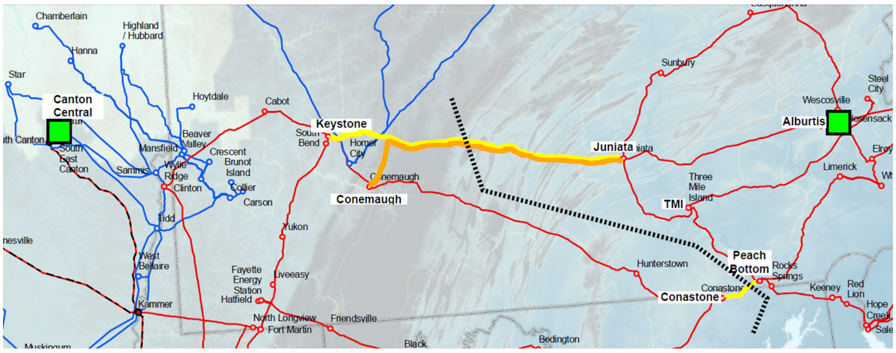


Figure 47: Central Transfer Interface of PJM with Critical Transmission Lines

The correlation between bus angle and power flow through central transfer interface of PJM plot is presented in Figure 48. The calculated correlation coefficient is 0.87 which shows there is a strong correlation between the interface power flow and the angle pair difference.

Figure 49 shows the central transfer interface of PJM with the monitored critical buses voltage.

The correlation coefficient results between monitored bus voltage and bus angle pair difference are presented in the following Table 33. It shows that the Keystone voltage has the strongest correlation with the monitored angle pair difference. It is also shown in the Figure 50.

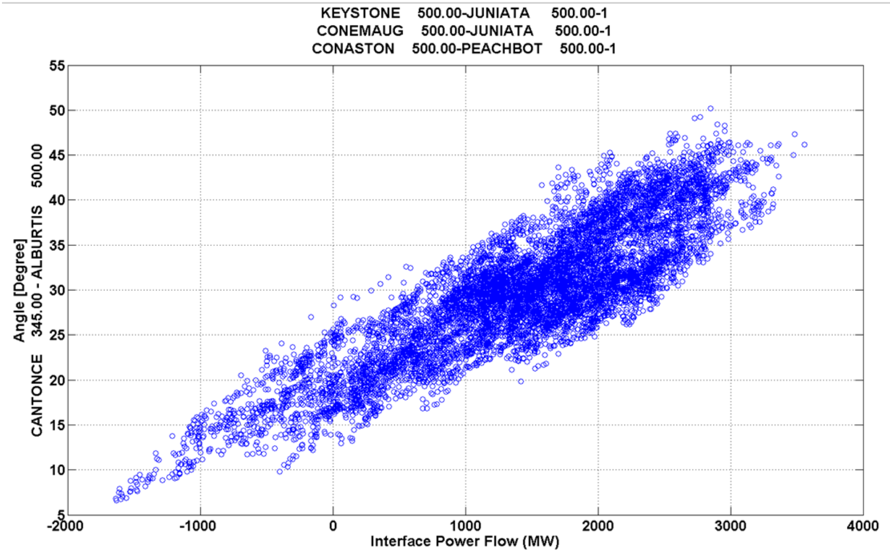


Figure 48: Correlation between Bus Angle (Canton Central-Alburtis) and Power Flow through Central Transfer Interface of PJM

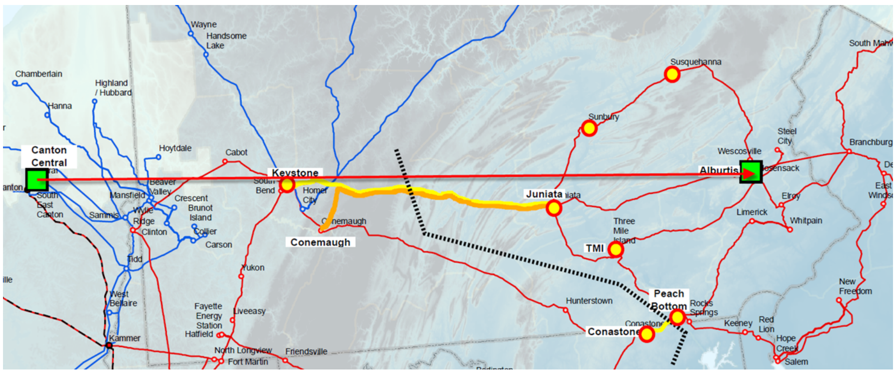


Figure 49: Central Transfer Interface of PJM with Critical Bus Voltage

Table 33: Correlation between Monitored Bus Voltage and Bus Angle for PJM Area Study

Bus Name	Correlation Coefficient
Sunbury 500kV	-0.65
Susquehanna 500kV	-0.39
Conastone 500kV	-0.22
Peach Bottom 500kV	-0.37
Juniata 500kV	-0.73
TMI 500kV	-0.6
Keystone 500kV	-0.74

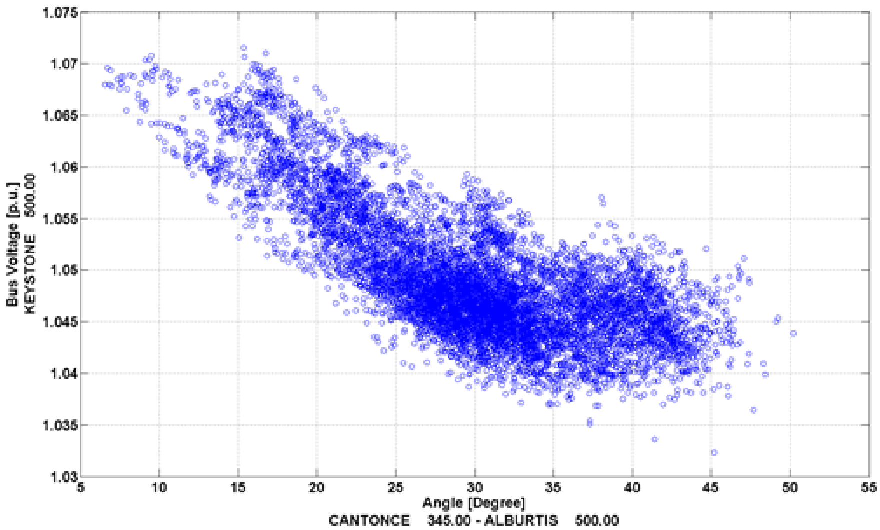


Figure 50: Correlation between Monitored Bus Voltage in Keystone and Monitored Bus Angle

Here is another example in MISO area. Similar study is performed in the St. Louis south interface of MISO area. There are two critical transmission lines in this area which is shown in Figure 51. The monitored bus angle pair is Labadie-Cumberland.

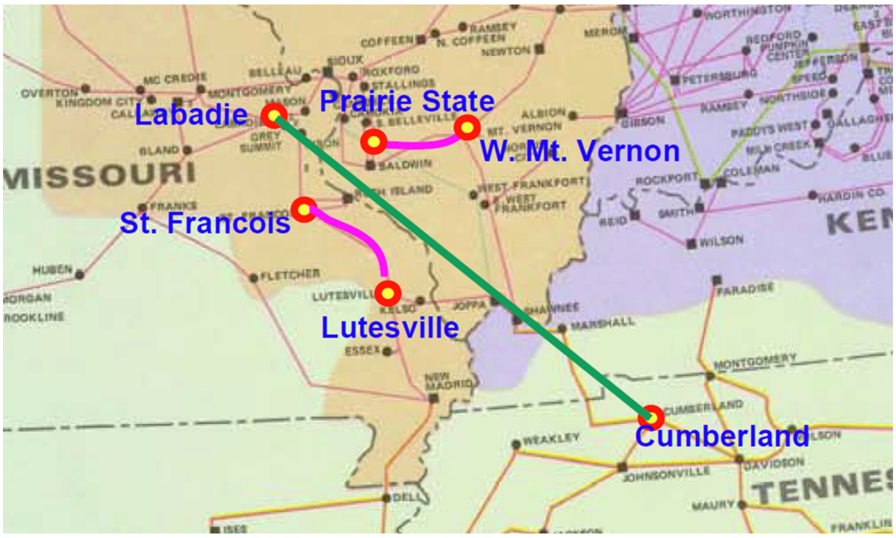


Figure 51: Critical Transmission Lines in St. Louis South Interface of MISO with Critical Transmission Lines

The correlation between bus angle and power flow through St. Louis south interface of MISO plot is presented in Figure 52. The calculated correlation coefficient is 0.90 which shows there is a strong correlation between the interface power flow and the angle pair difference.

Figure 53 shows the map of central transfer interface of MISO with the monitored critical buses voltage.

The correlation coefficient results between monitored bus voltage and bus angle pair difference are presented in the following Table 34. It shows that the West Mount Vernon 345kV bus voltage has the strongest correlation with the monitored angle pair difference. It is also shown in the Figure 50.

Both correlation studies show strong correlation between monitored bus angle and interface MW flow. The correlations between monitored bus angle and bus voltages vary.

For all the selected angle pairs, a complete correlation study is performed between the voltage angle and transmission power flow, and between the voltage angle and bus voltage. Appendix A.7 provides the top 10 transmission lines ranked by correlation coefficients between the selected angle pairs and MW flow. The top 10 Buses ranked by correlation coefficients between selected bus angle and voltage are also provided.

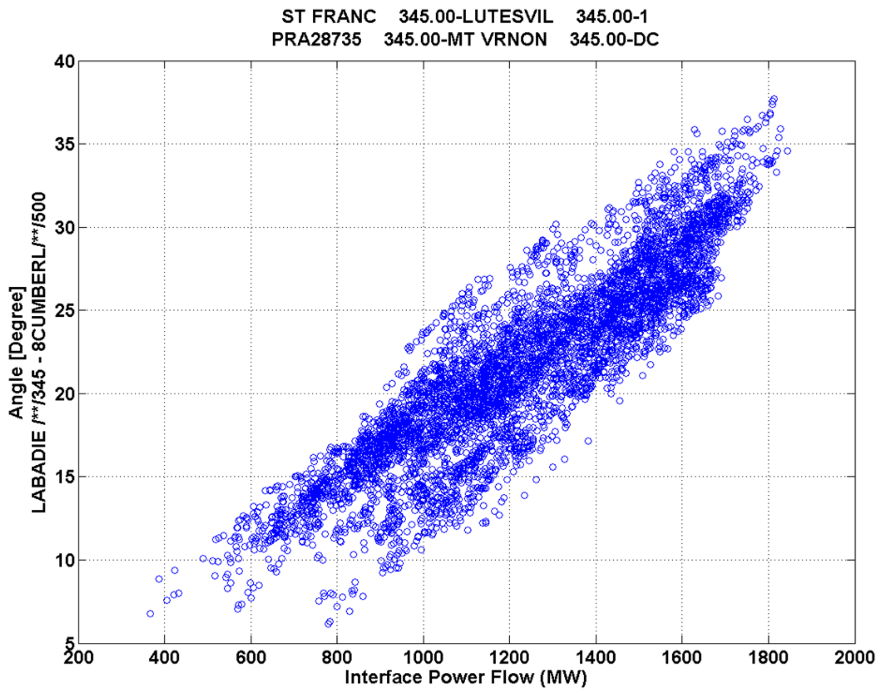


Figure 52: Correlation between Bus Angle (Canton Central-Alburtis) and Power Flow through Central Transfer Interface of PJM

Table 34: Correlation between Monitored Bus Voltage and Bus Angle for MISO Area Study

Bus Name	Correlation Coefficient
St Francois 345kV	-0.68
Prairie State 345kV	-0.51
Lutesville 345kV	-0.74
West Mount Vernon 345kV	-0.77
BALDWIN 345kV	-0.07
Shawnee 345kV	-0.61
East West Frankfort 345kV	-0.7

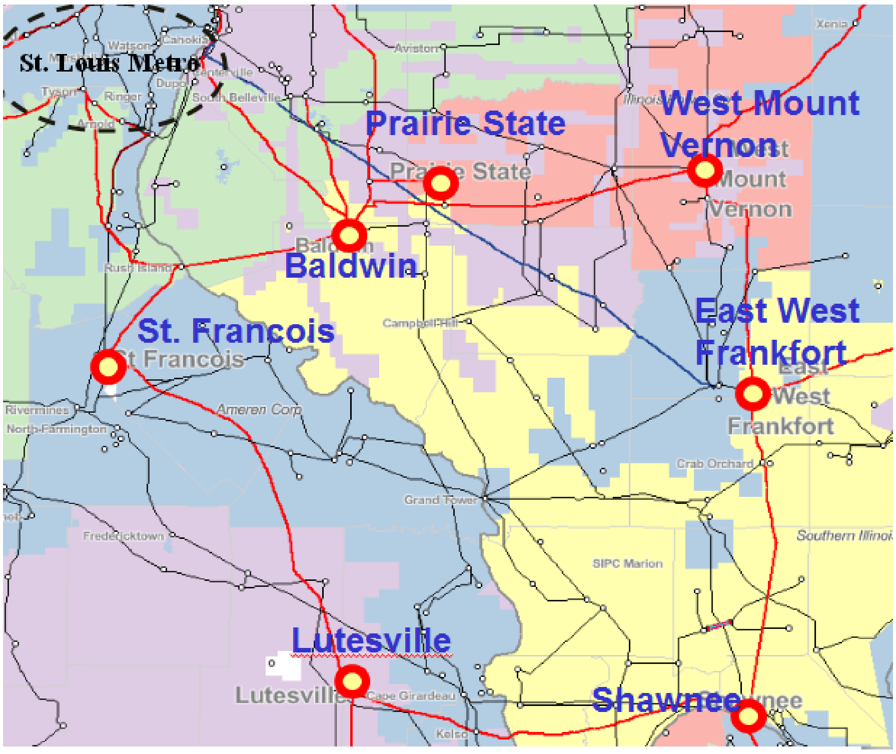


Figure 53: St. Louis South Interface of MISO with Critical Bus Voltage

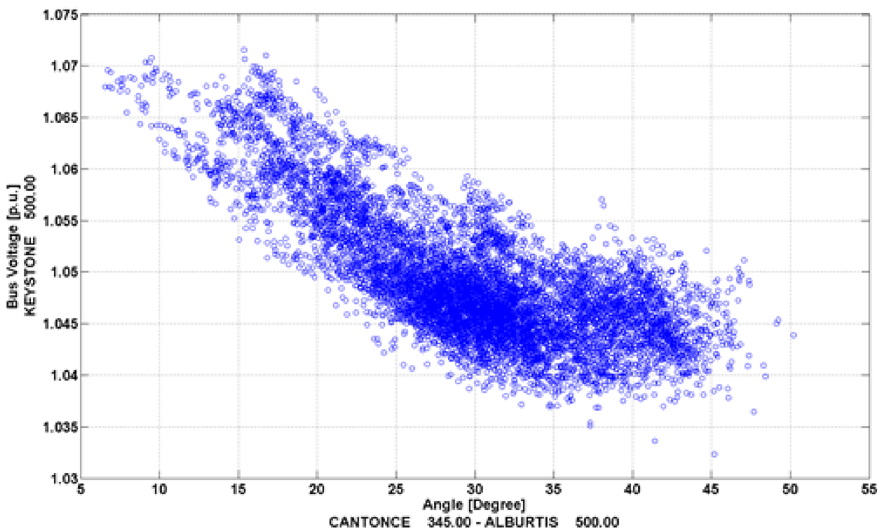


Figure 54: Correlation between Monitored Bus Voltage in West Mount Vernon and Monitored Bus Angle

9.5 Conclusions and Observations

In this section, statistical analysis was conducted on the data extracted from the SE data from four ISOs. There are 22 wide area angle pairs across ISOs are requested to be analyzed by Technical Advisor Group. Reference ranges for monitoring were proposed for each of the wide area angle pairs. In this section, the feasibility of data stitching is studied. Since the state estimator data is not time synchronized, a lot of effort has to be made to combine data from different ISOs. With different time stamp and different sampling rate, calculation error is introduced because of interpolation. It is recommended to use the angle difference data from the Phasor System data rather than the state estimator data. Co-relation analysis of angle pairs with power flow and bus voltage are studied. Co-relation analysis of angle pairs with power flow on paths shows a strong co-relation. Angle pair monitoring will enable the operators assess system stress as a backup alternative to monitoring power flow from SE data. Co-relation analysis of angle pairs with bus voltage showed a poor co-relation.

10 SUMMARY OF KEY CONCLUSION AND FINDINGS

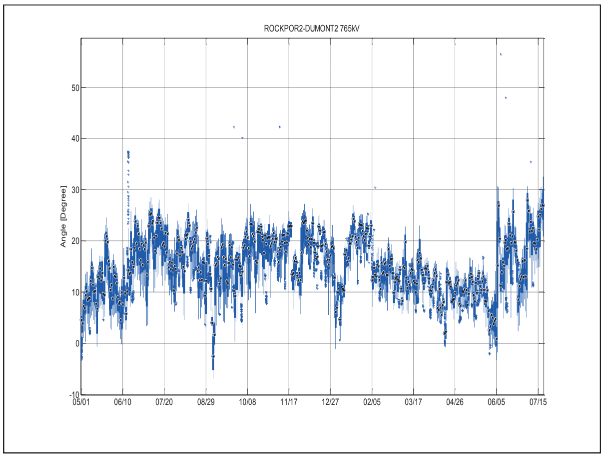
- SE data has been used to obtain initial results in absence of the PMU data as SE data was readily available. The data has been useful in establishing high/low range for different angle pairs. The ranges can be used to alert operators if system is subjected to abnormal loading situation.
- SE data has been useful for establishing high/low reference range within the ISO region. For inter-ISO angle pairs, it is not feasible to stitch SE data. Time synchronized phasor system data will be used to establish high/low ranges for inter-ISO angle pairs.
- Co-relation analysis of angle pairs with power flow on paths shows a strong co-relation. Angle pair monitoring will enable the operators assess system stress as a backup alternative to monitoring power flow from SE data.
- Co-relation analysis of angle pairs with bus voltage showed a poor co-relation.
- Analysis of some outliers has shown, that some outliers were caused by contingencies, while some others were caused by poor SE solutions.

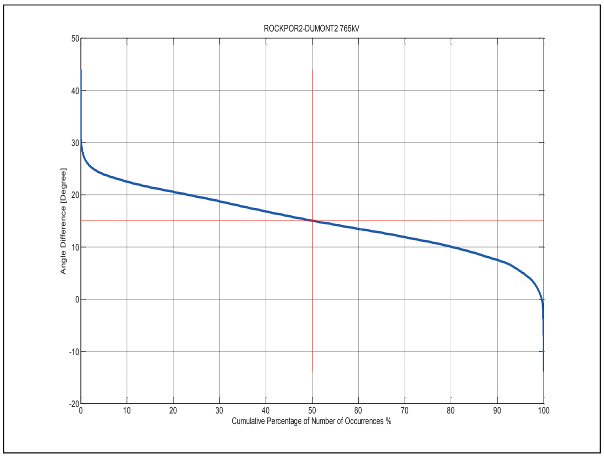
References

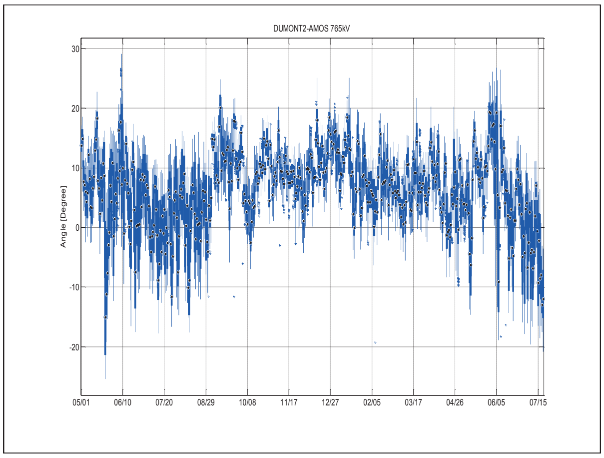
[1] F.E.Grubbs. Procedures for detecting outlying observations in samples. *Technometrics*, 11:1–21, 1969.

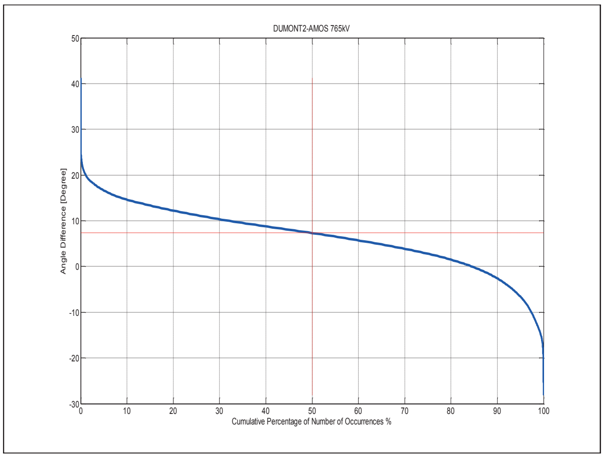
A APPENDIX

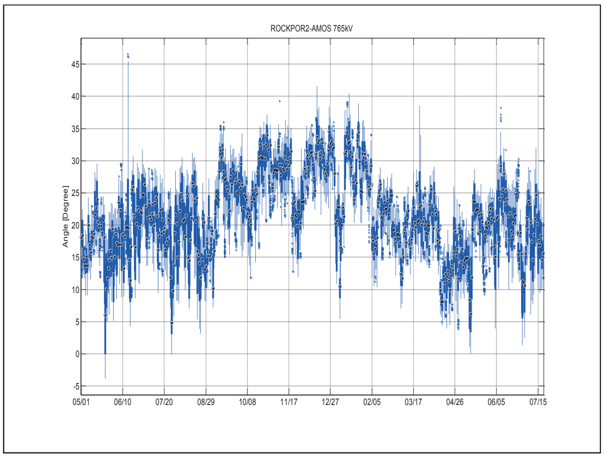
A.1 PJM Selected Angle Pairs Box Whisker Plots and Time Duration Plots

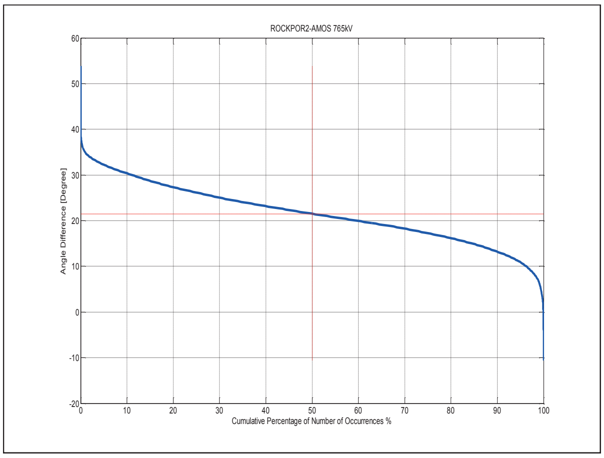


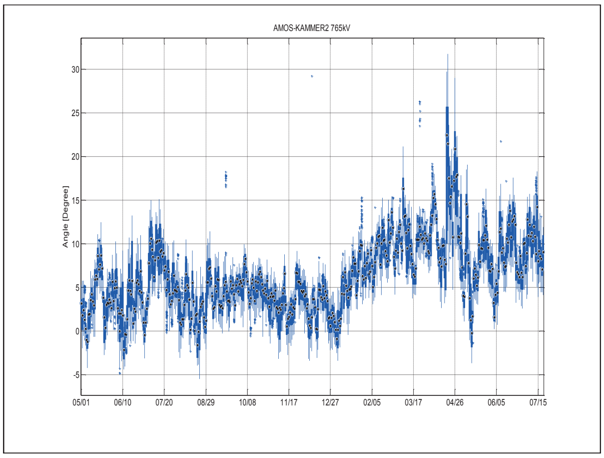


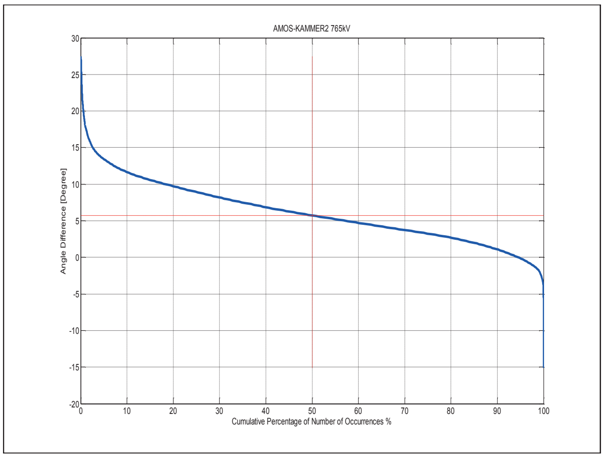


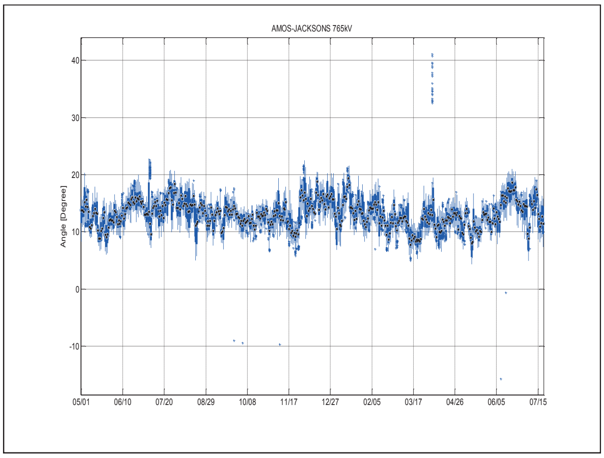


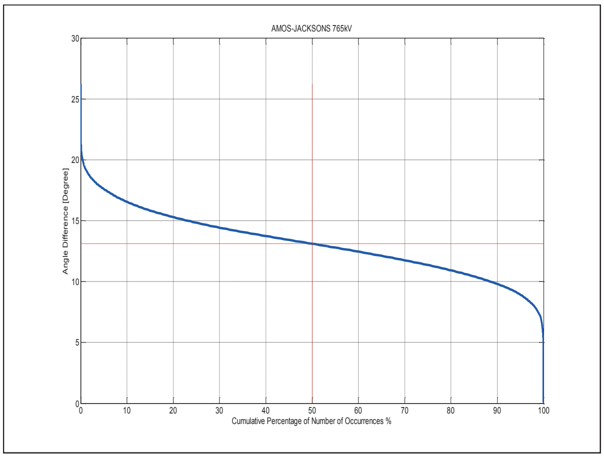

ROCKPOR2-AMOS 765kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15

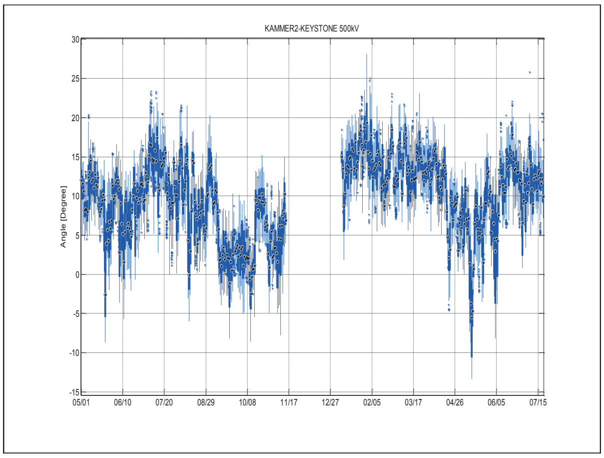

ROCKPOR2-AMOS 765kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

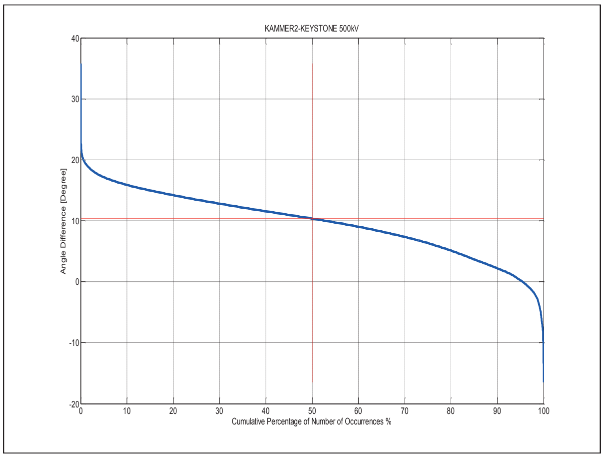

AMOS-KAMMER2 765kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15

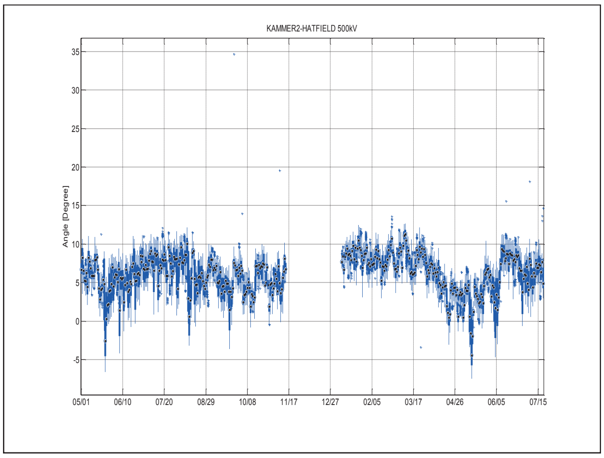

AMOS-KAMMER2 765kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

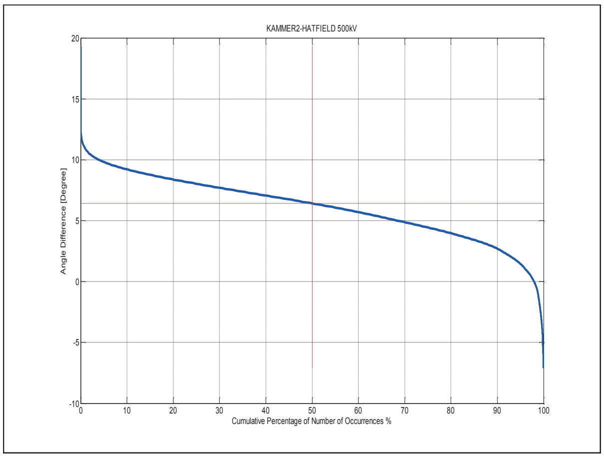

AMOS-JACKSONS 765kV
Angle [Degree]
05/01
06/10
07/20
08/29
10/08
11/17
12/27
02/05
03/17
04/26
06/05
07/15

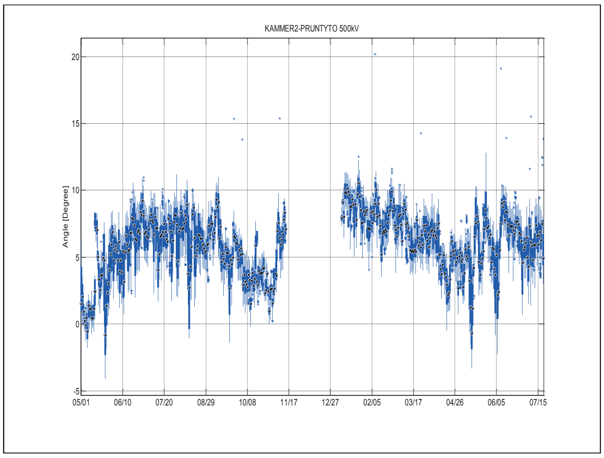

AMOS-JACKSONS 765kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


KAMMER2-KEYSTONE 500kV
Angle [Degree]
05/01
06/10
07/20
08/29
10/08
11/17
12/27
02/05
03/17
04/26
06/05
07/15


KAMMER2-KEYSTONE 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


KAMMER2-HATFIELD 500kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15


KAMMER2-HATFIELD 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


KAMMER2-PRUNTYTO 500kV
Angle [Degree]
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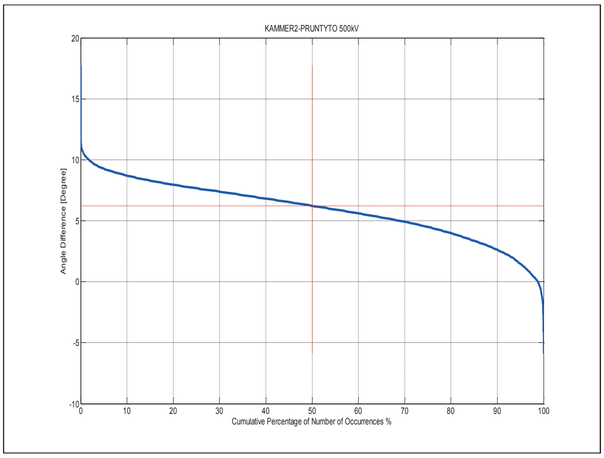
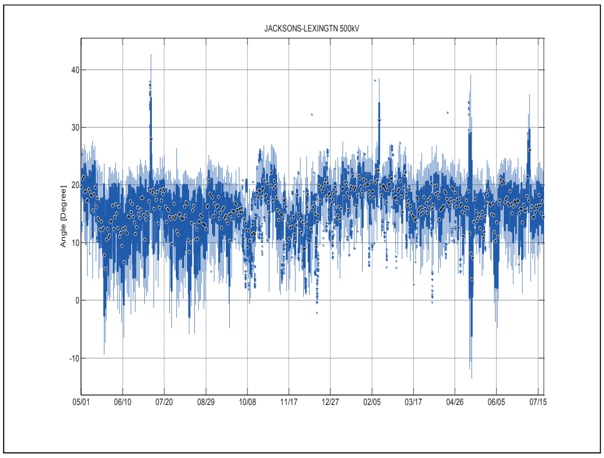
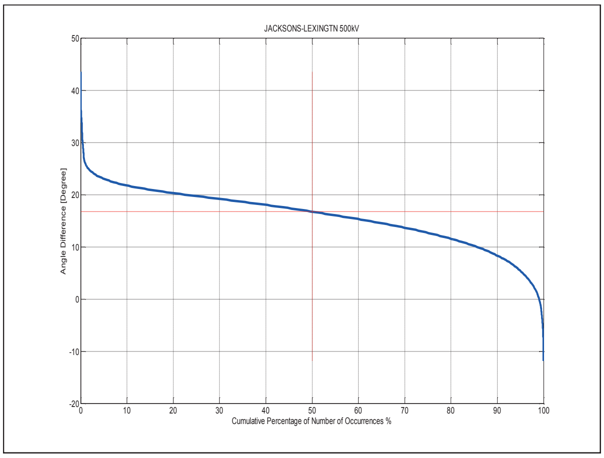
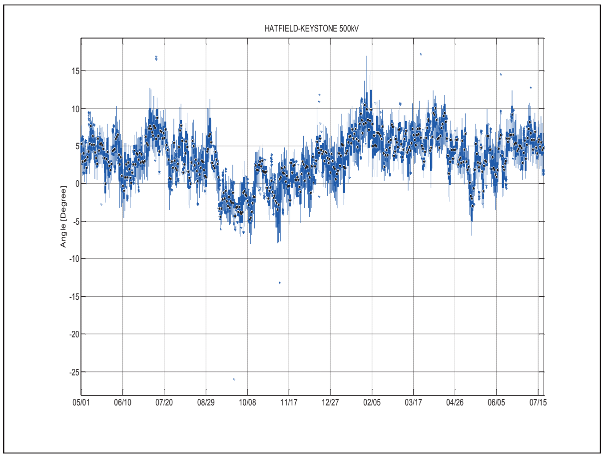
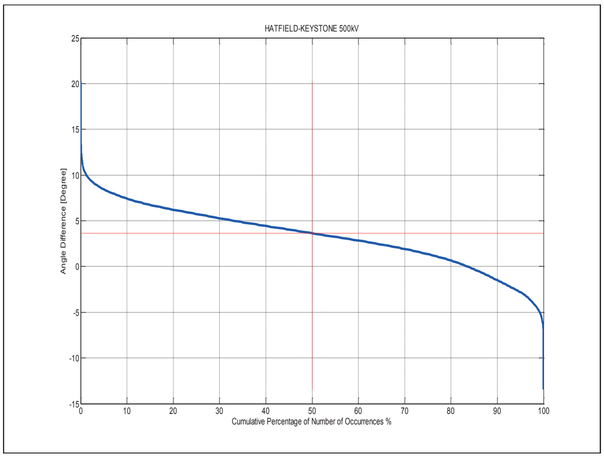

KAMMER2-PRUNTYTO 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


JACKSONS-LEXINGTN 500kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15


JACKSONS-LEXINGTN 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


HATFIELD-KEYSTONE 500kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15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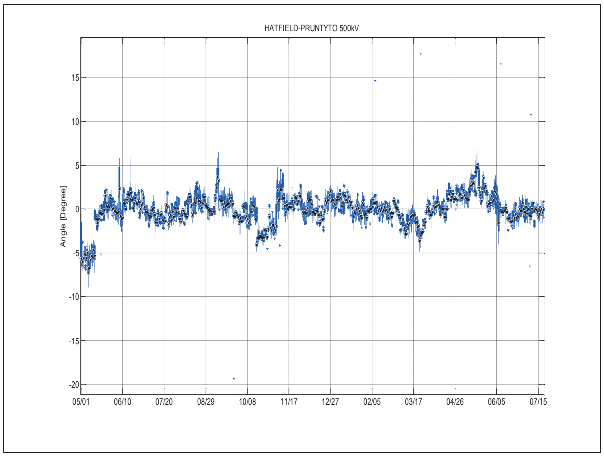
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


HATFIELD-PRUNTYTO 500kV
Angle [Degree]
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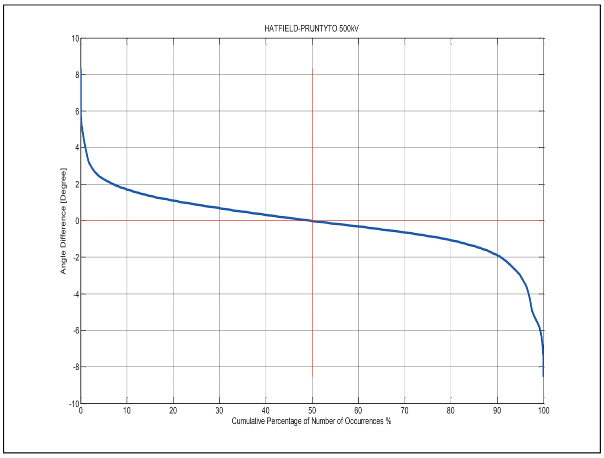
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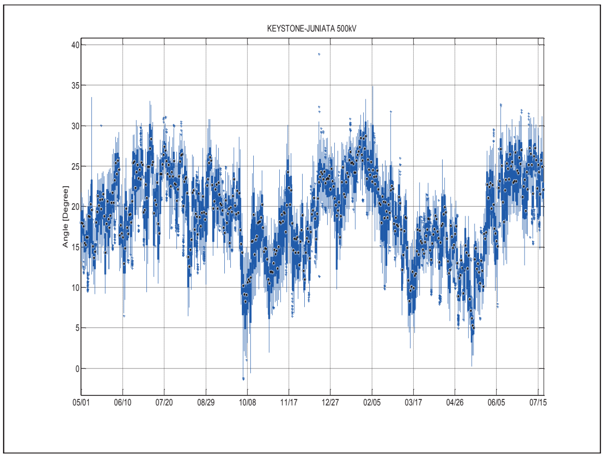
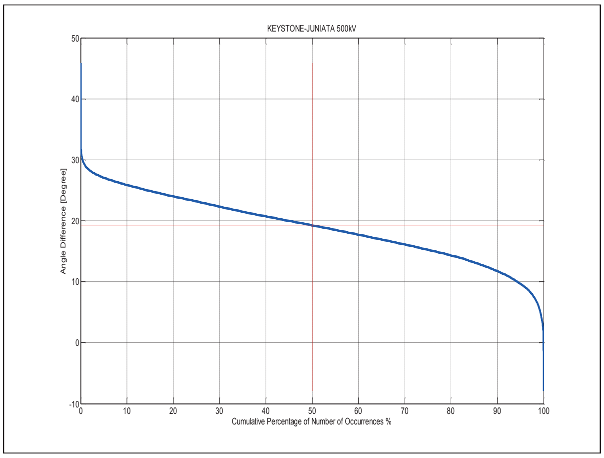
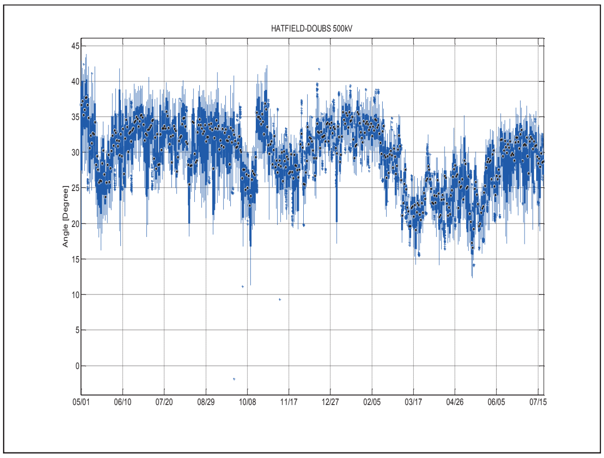
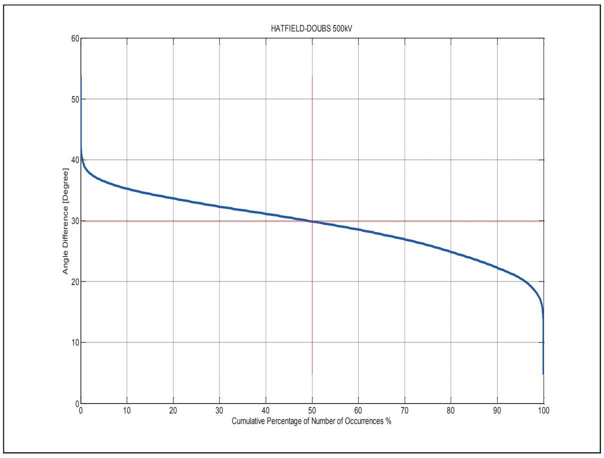
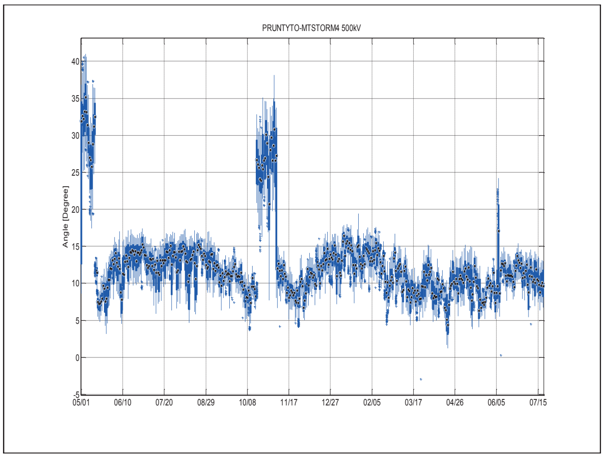
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

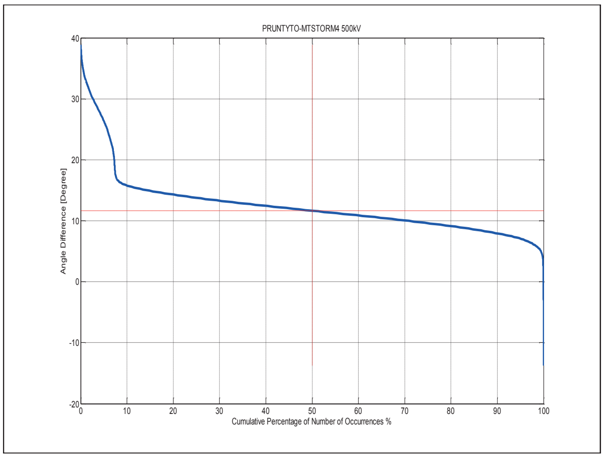

KEYSTONE-JUNIATA 500kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15

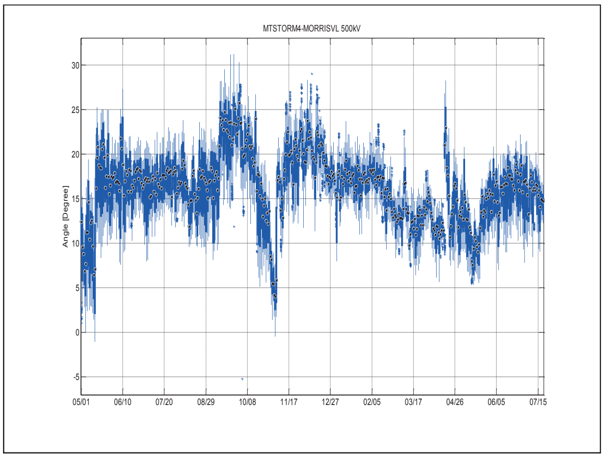

KEYSTONE-JUNIATA 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


HATFIELD-DOUBS 500kV
Angle [Degree]


HATFIELD-DOUBS 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


PRUNTYTO-MTSTORM4 500kV
Angle [Degree]


PRUNTYTO-MTSTORM4 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


MTSTORM4-MORRISVL 500kV
Angle [Degree]
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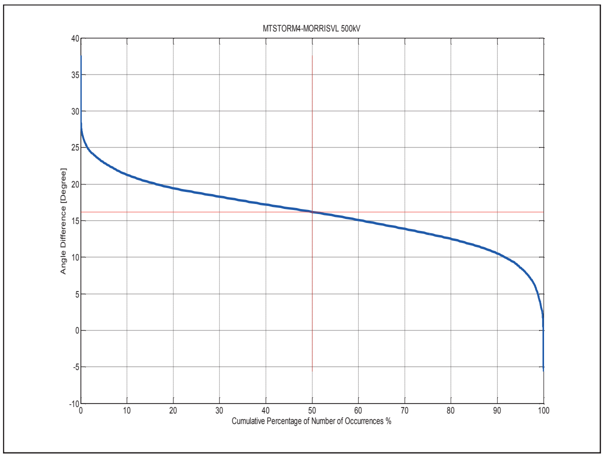
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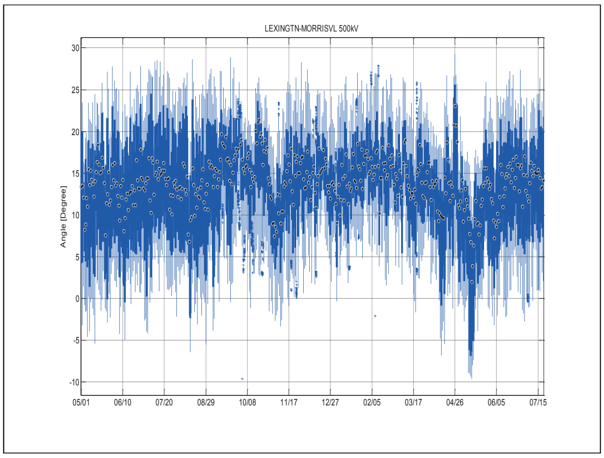
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


LEXINGTN-MORRISVL 500kV
Angle [Degree]
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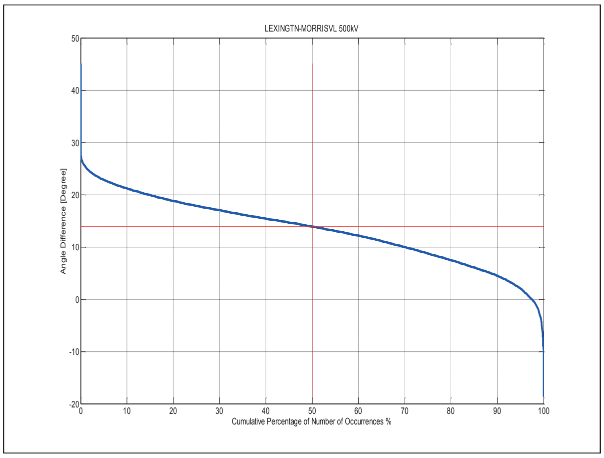
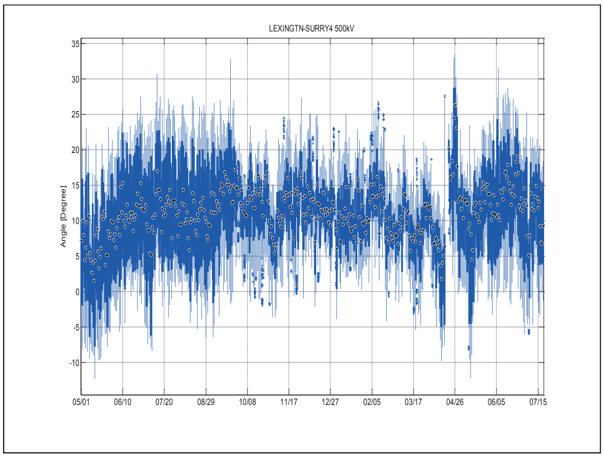
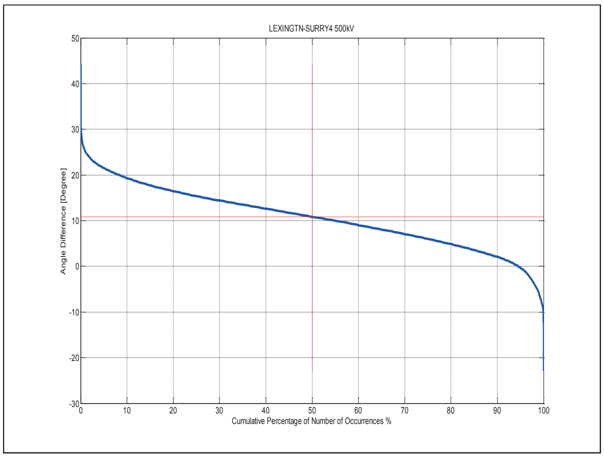
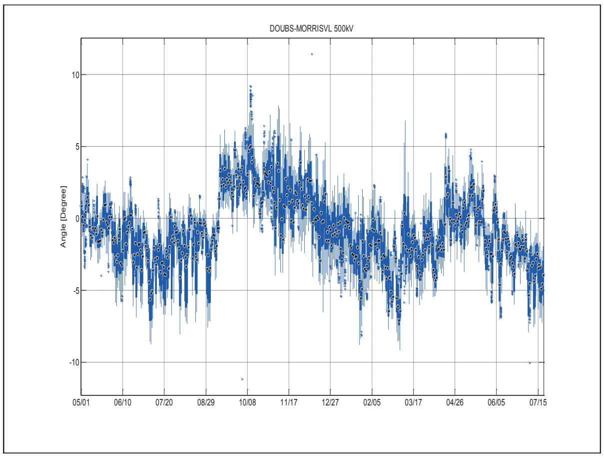
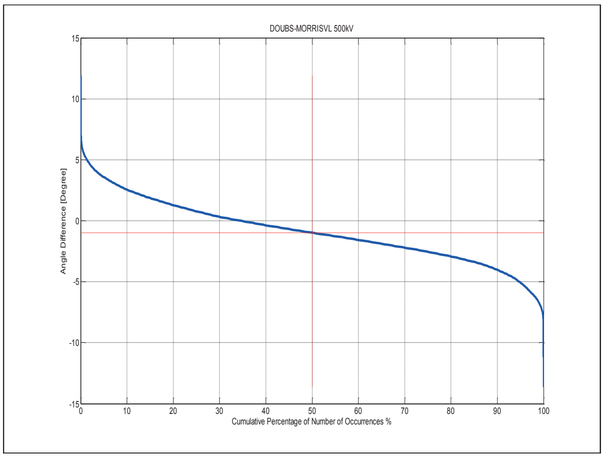
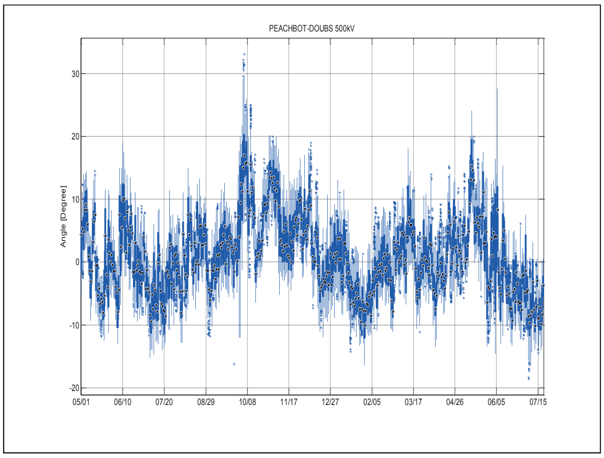

LEXINGTN-MORRISVL 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

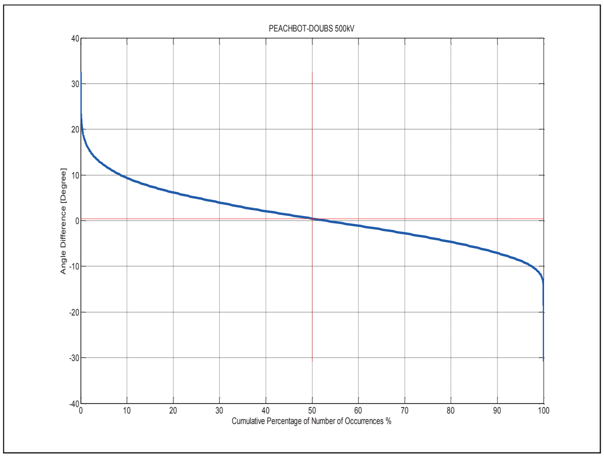

LEXINGTN-SURRY4 500kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15

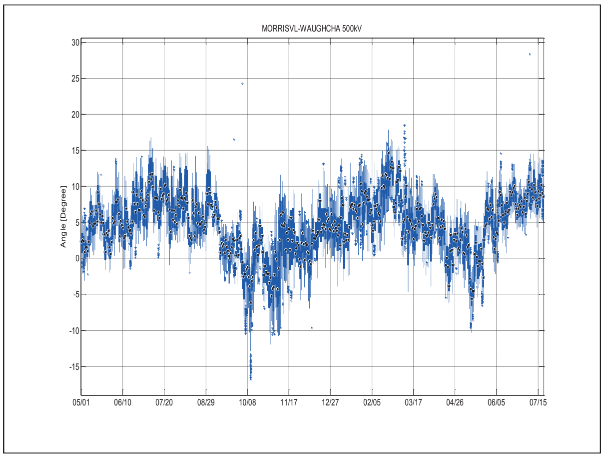

LEXINGTN-SURRY4 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

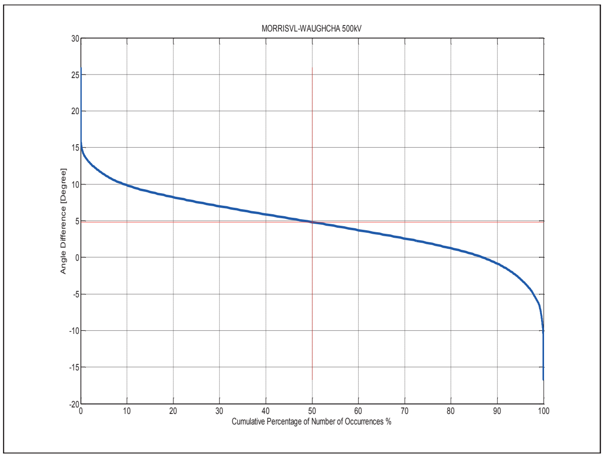

DOUBS-MORRISVL 500kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15

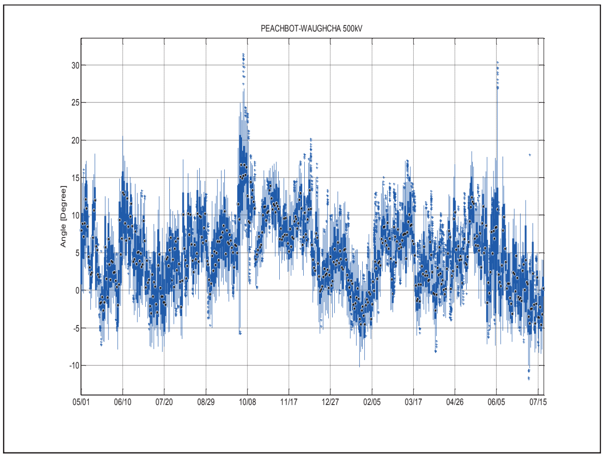

DOUBS-MORRISVL 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


PEACHBOT-DOUBS 500kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15


PEACHBOT-DOUBS 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


MORRISVL-WAUGHCHA 500kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15


MORRISVL-WAUGHCHA 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


PEACHBOT-WAUGHCHA 500kV
Angle [Degree]
05/01
06/10
07/20
08/29
10/08
11/17
12/27
02/05
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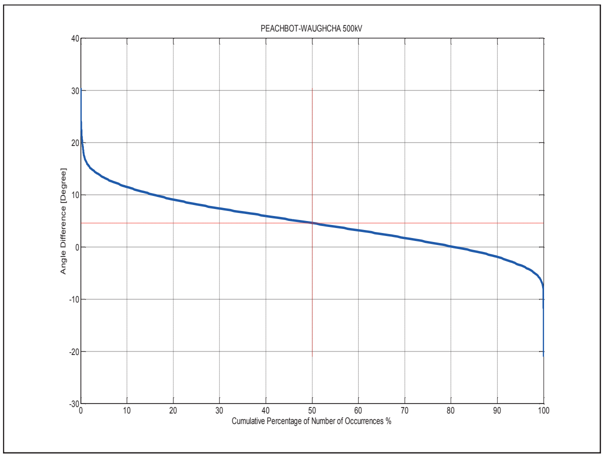
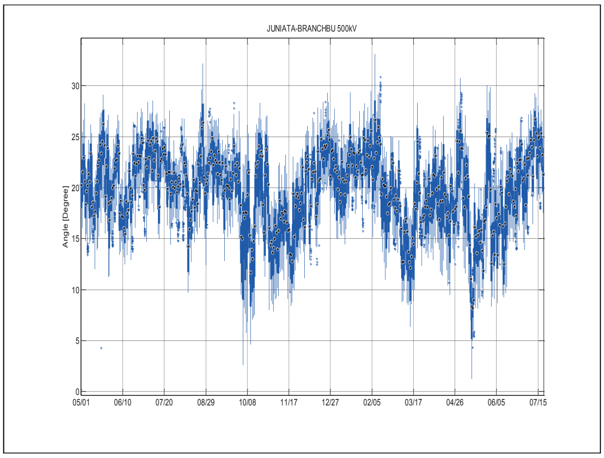
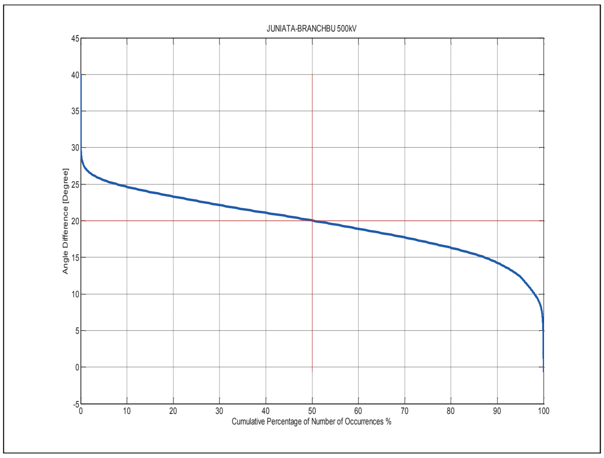
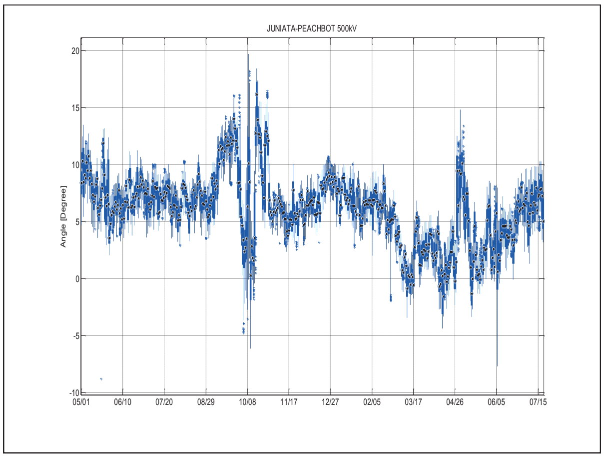
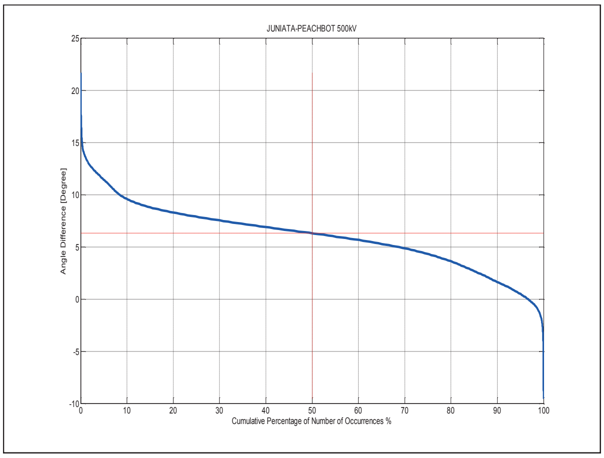
04/26
06/05
07/15

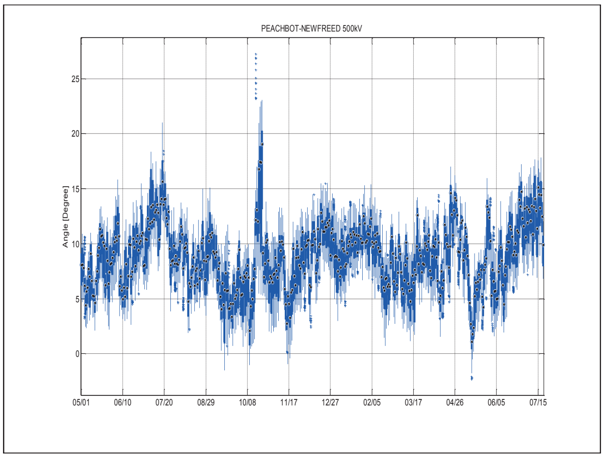

PEACHBOT-WAUGHCHA 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

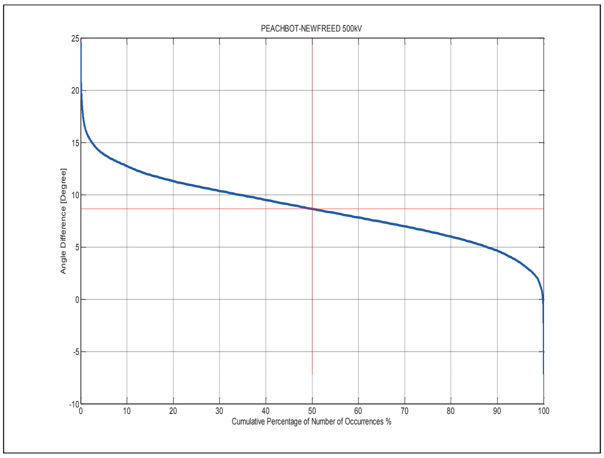

JUNIATA-BRANCHBU 500kV
Angle [Degree]
05/01
06/10
07/20
08/29
10/08
11/17
12/27
02/05
03/17
04/26
06/05
07/15

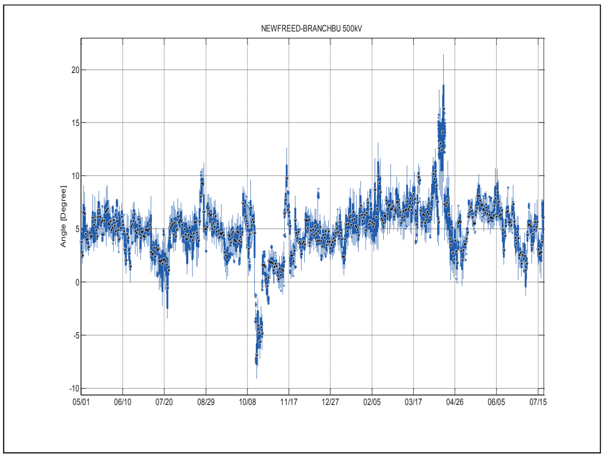

JUNIATA-BRANCHBU 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

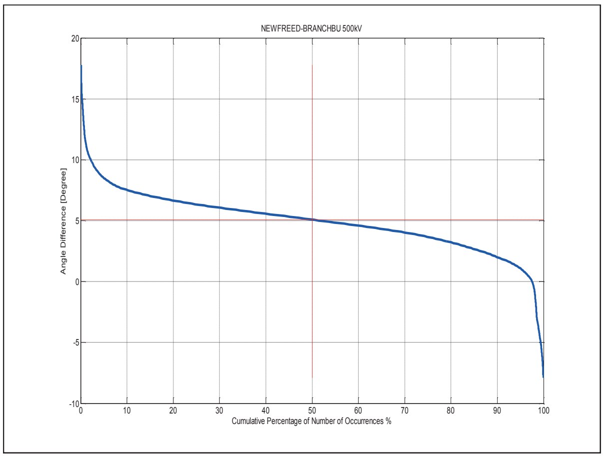

JUNIATA-PEACHBOT 500kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15

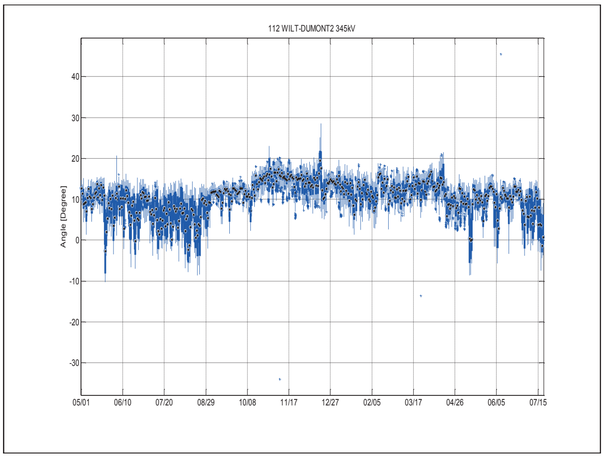

JUNIATA-PEACHBOT 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

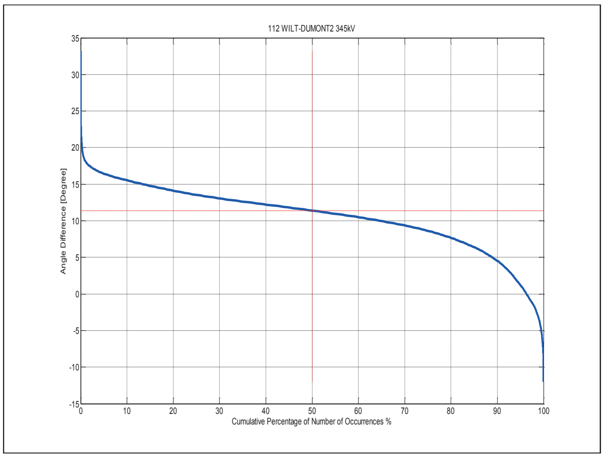

PEACHBOT-NEWFREED 500kV
Angle [Degree]
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15

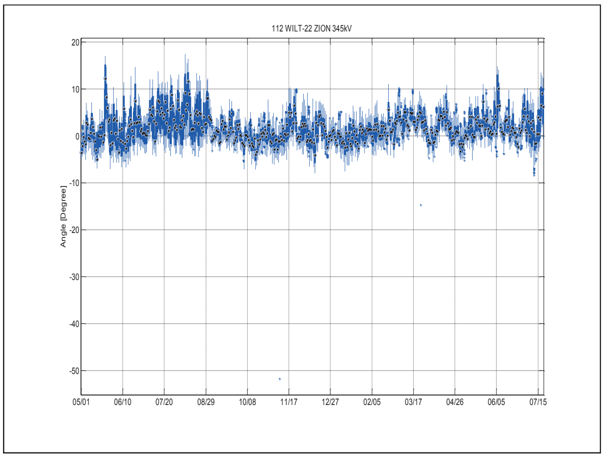

PEACHBOT-NEWFREED 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

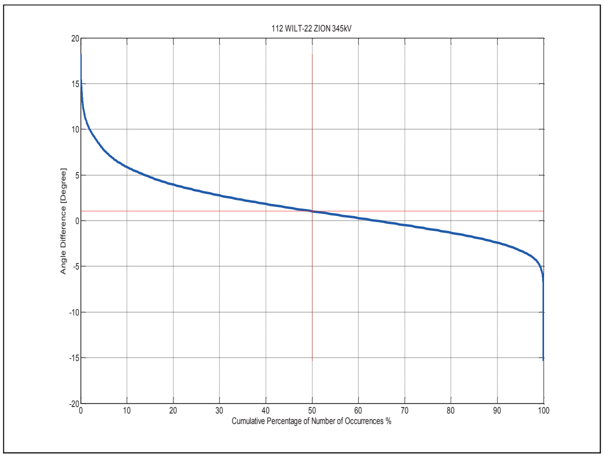

NEWFREED-BRANCHBU 500kV
Angle [Degree]

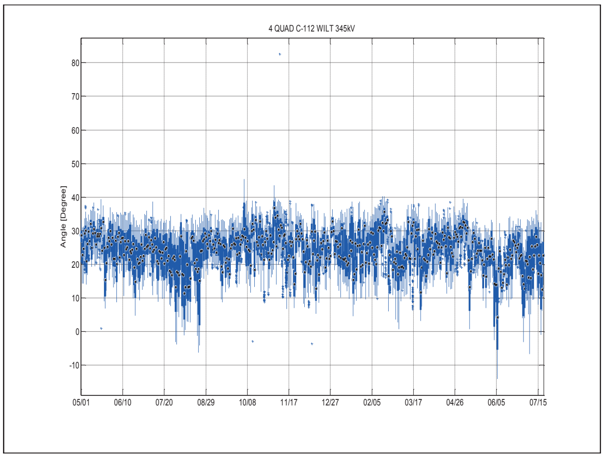

NEWFREED-BRANCHBU 500kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

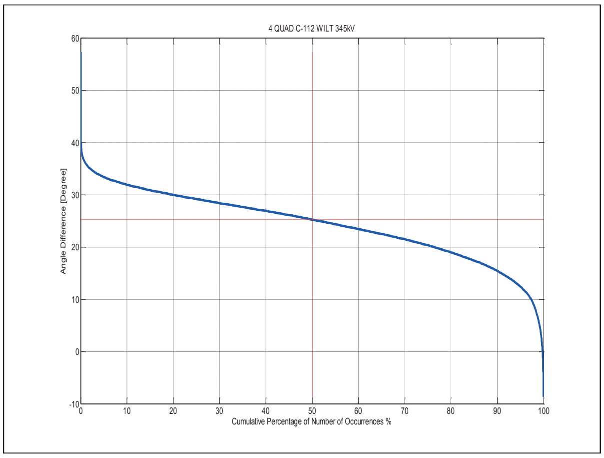

112 WILT-DUMONT2 345kV
Angle [Degree]

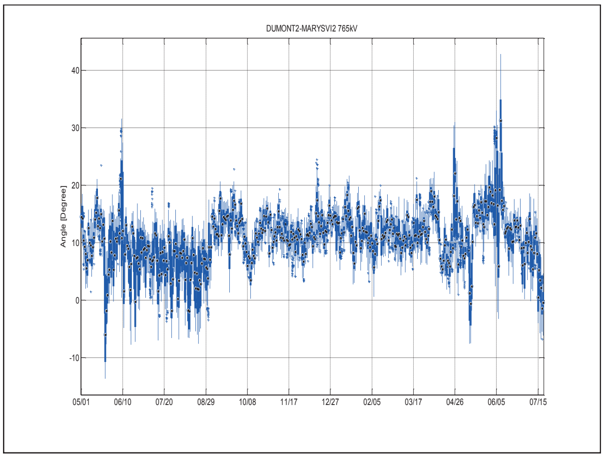

112 WILT-DUMONT2 345kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

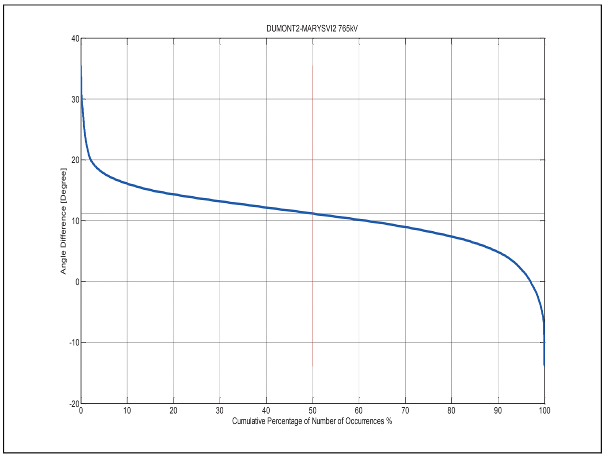

112 WILT-22 ZION 345kV
Angle [Degree]

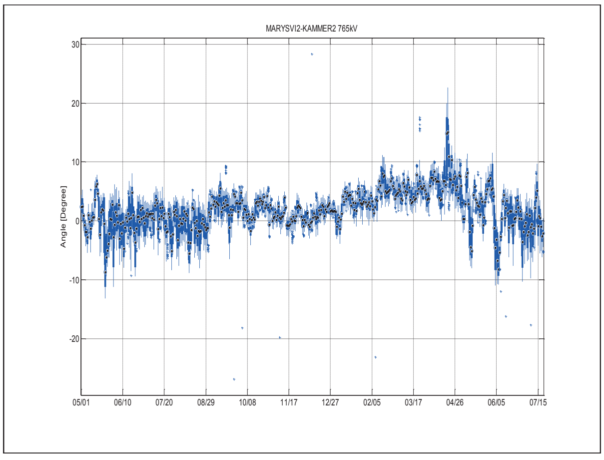

112 WILT-22 ZION 345kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

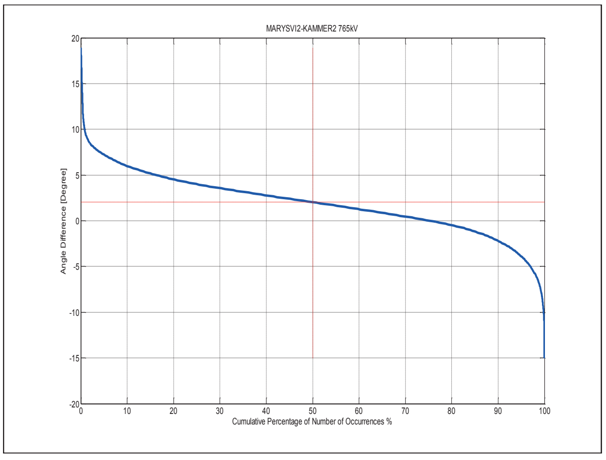

4 QUAD C-112 WILT 345kV
Angle [Degree]

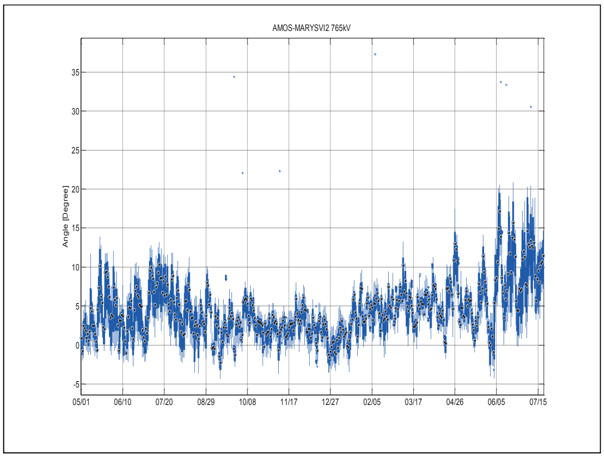

4 QUAD C-112 WILT 345kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

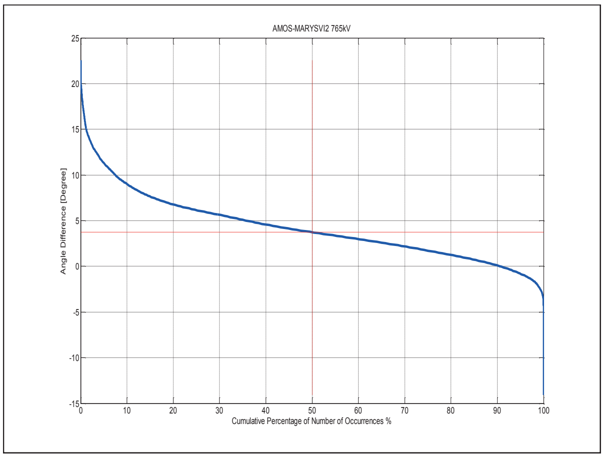

DUMONT2-MARYSVI2 765kV
Angle [Degree]
05/01
06/10
07/20
08/29
10/08
11/17
12/27
02/05
03/17
04/26
06/05
07/15

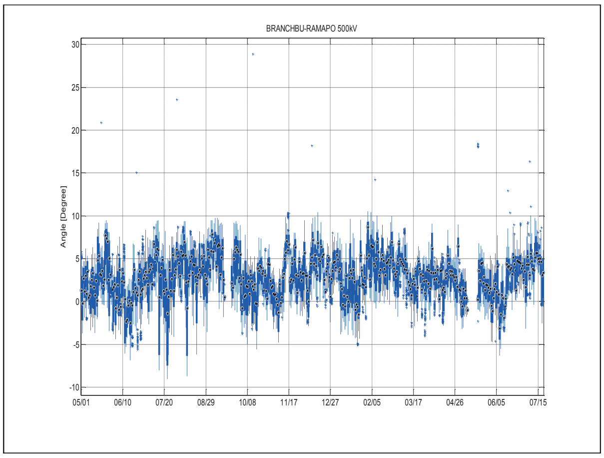

DUMONT2-MARYSVI2 765kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

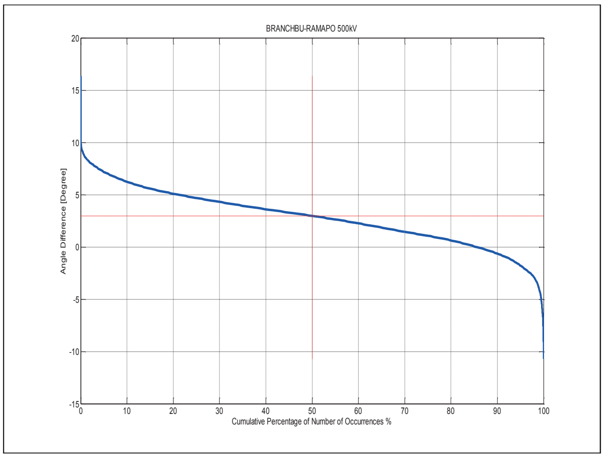

MARYSVI2-KAMMER2 765kV
Angle [Degree]
05/01
06/10
07/20
08/29
10/08
11/17
12/27
02/05
03/17
04/26
06/05
07/15

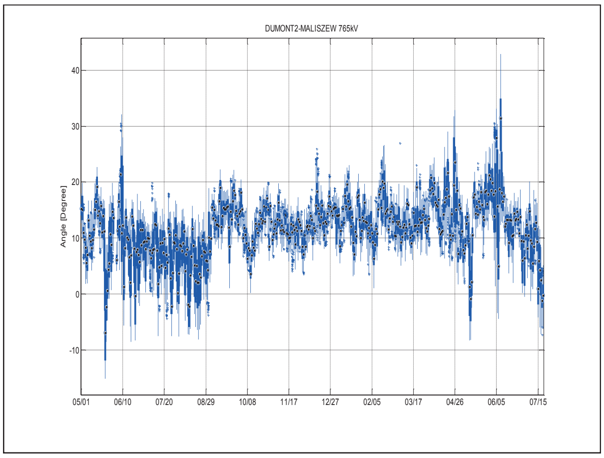

MARYSVI2-KAMMER2 765kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

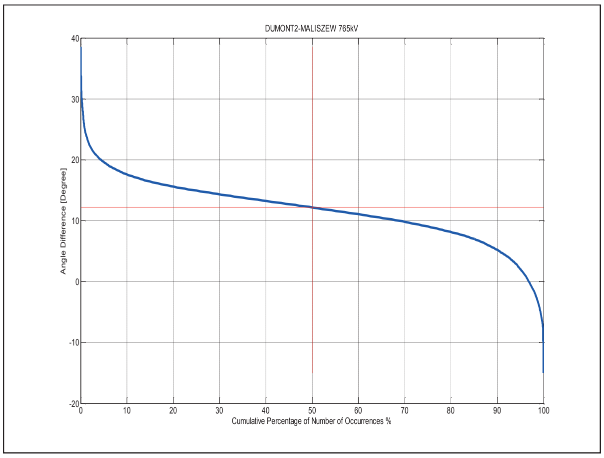

AMOS-MARYSVI2 765kV
Angle [Degree]
35
30
25
20
15
10
5
0
-5
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15

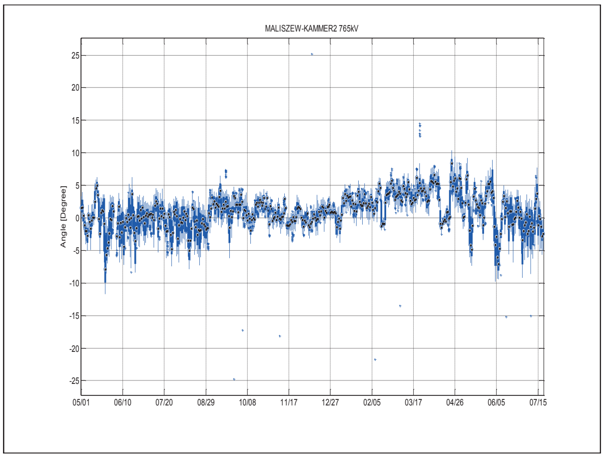

AMOS-MARYSVI2 765kV
Angle Difference [Degree]
25
20
15
10
5
0
-5
-10
-15
0 10 20 30 40 50 60 70 80 90 100
Cumulative Percentage of Number of Occurrences %

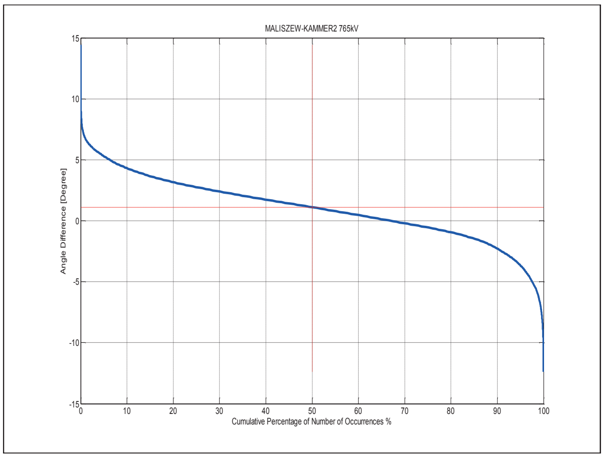

BRANCHBU-RAMAPO 500kV
Angle [Degree]
30
25
20
15
10
5
0
-5
-10
05/01 06/10 07/20 08/29 10/08 11/17 12/27 02/05 03/17 04/26 06/05 07/15

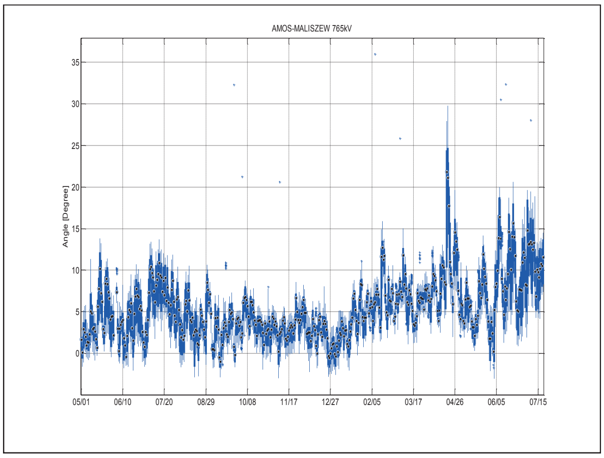

BRANCHBU-RAMAPO 500kV
Angle Difference [Degree]
20
15
10
5
0
-5
-10
-15
0 10 20 30 40 50 60 70 80 90 100
Cumulative Percentage of Number of Occurrences %

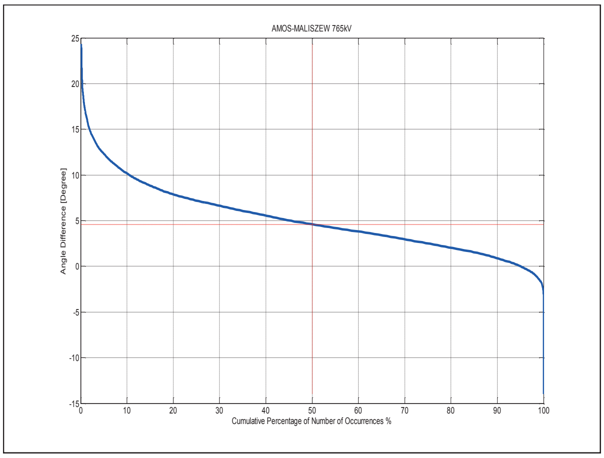

DUMONT2-MALISZEW 765kV
Angle [Degree]


DUMONT2-MALISZEW 765kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

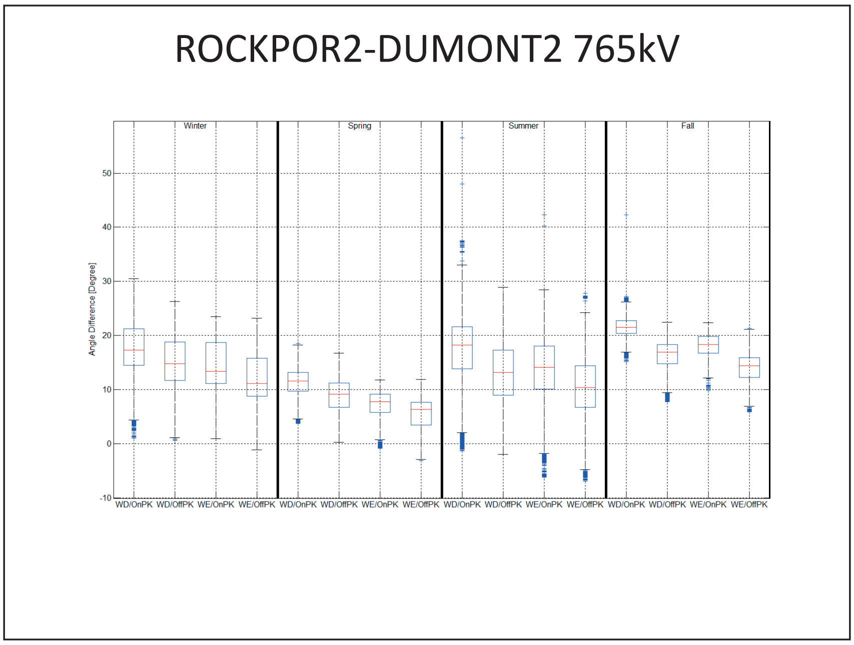

MALISZEW-KAMMER2 765kV
Angle [Degree]

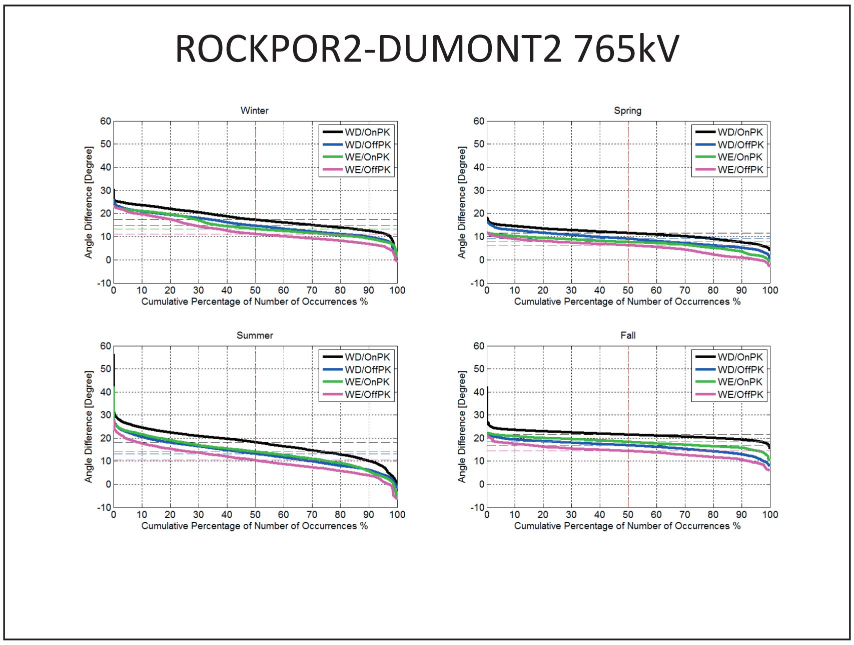

MALISZEW-KAMMER2 765kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


AMOS-MALISZEW 765kV
Angle [Degree]
35
30
25
20
15
10
5
0
05/01
06/10
07/20
08/29
10/08
11/17
12/27
02/05
03/17
04/26
06/05
07/15

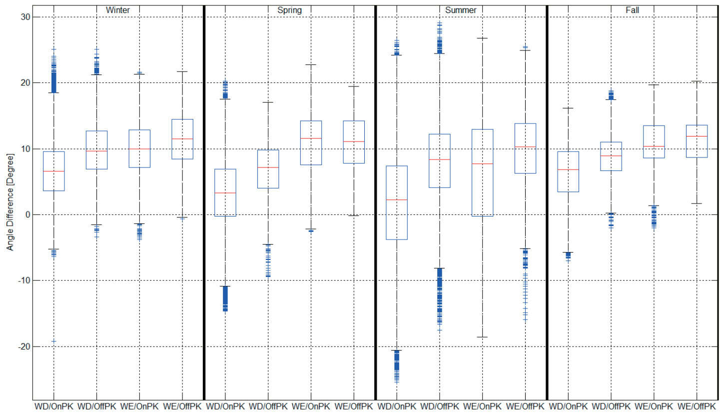

AMOS-MALISZEW 765kV
Angle Difference [Degree]
25
20
15
10
5
0
-5
-10
-15
0
10
20
30
40
50
60
70
80
90
100
Cumulative Percentage of Number of Occurrences %

A.2 PJM Selected Angle Pairs Box Whisker Plots and Time Duration Plots Grouped By Seasons

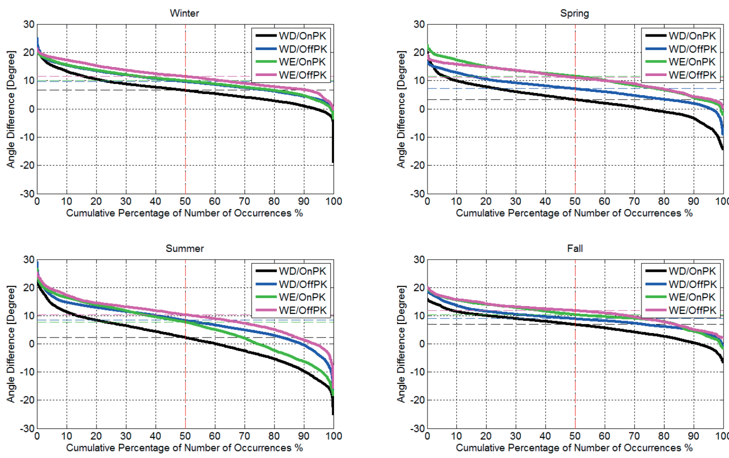




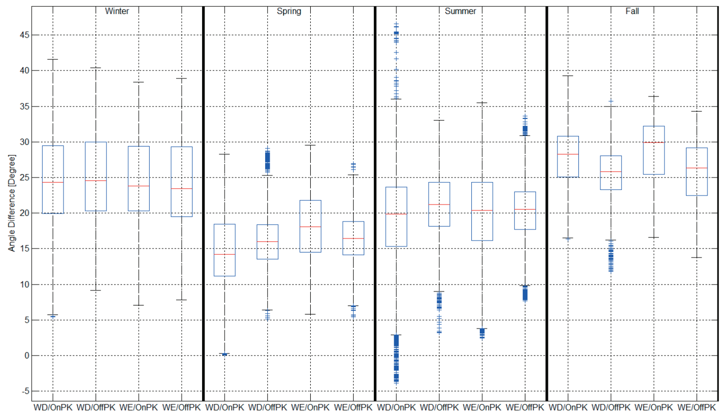
DUMONT2-AMOS 765kV



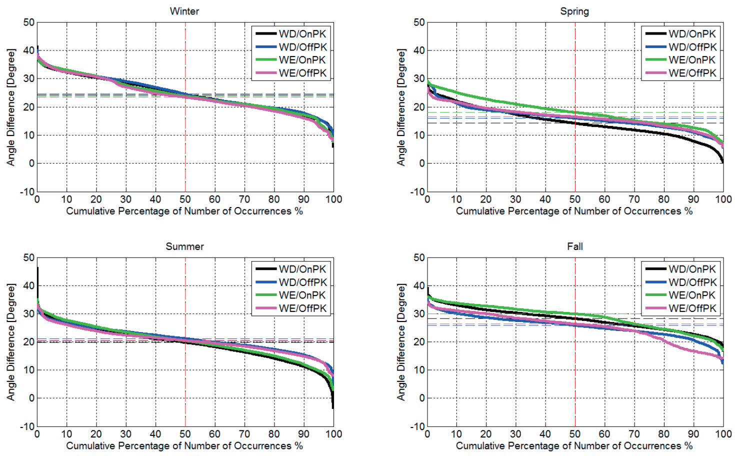
DUMONT2-AMOS 765kV



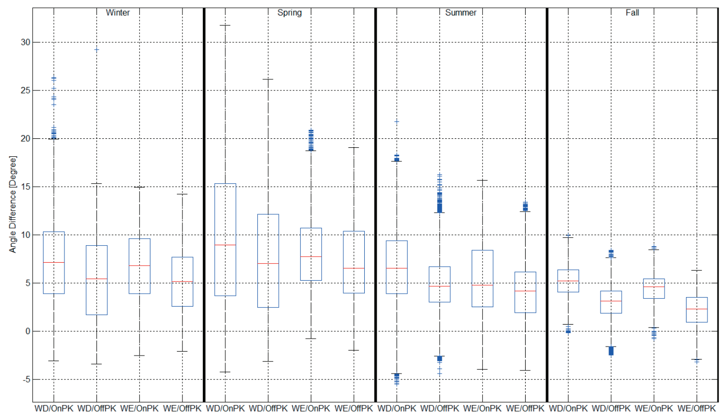
ROCKPOR2-AMOS 765kV



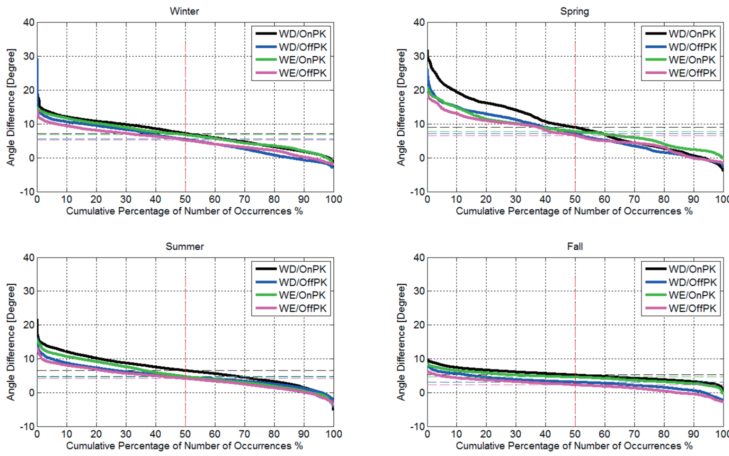
ROCKPOR2-AMOS 765kV

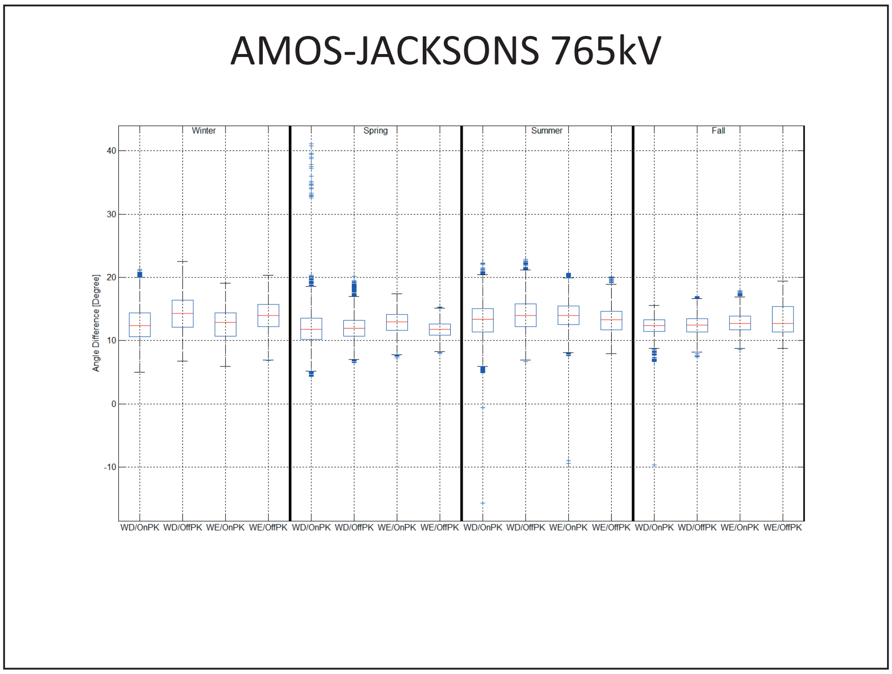


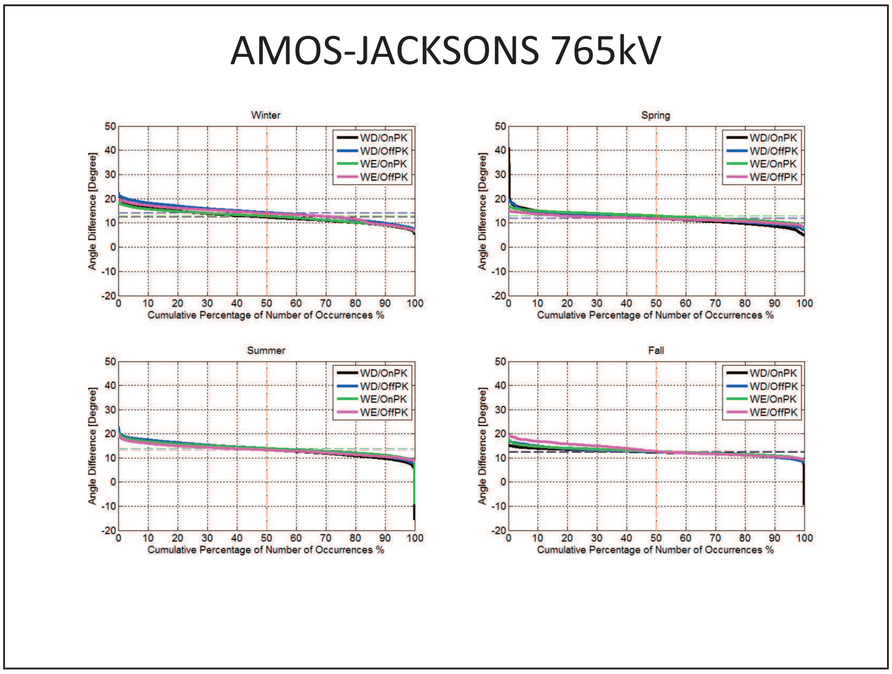
AMOS-KAMMER2 765kV



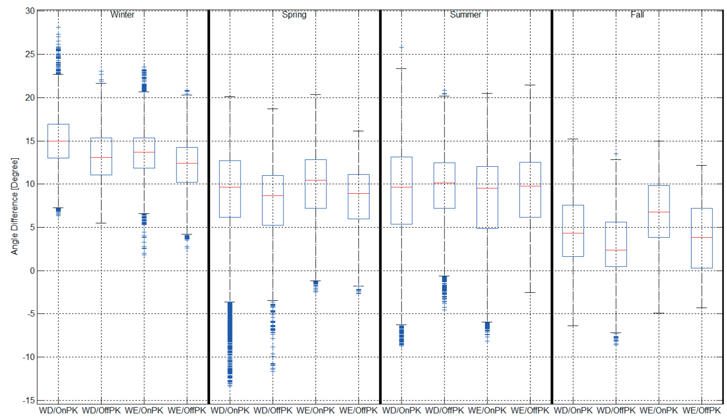
AMOS-KAMMER2 765kV



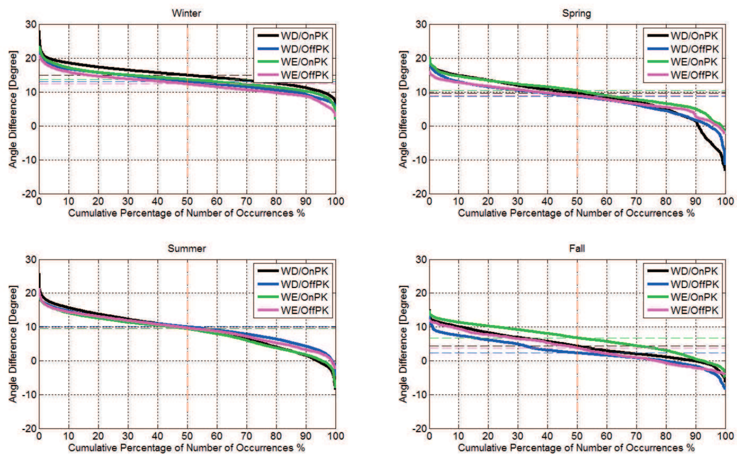

AMOS-JACKSONS 765kV
Winter
Spring
Summer
Fall
Angle Difference [Degree]
WD/OnPK WD/OffPK WE/OnPK WE/OffPK


AMOS-JACKSONS 765kV
Winter
Spring
Summer
Fall
WD/OnPK
WD/OffPK
WE/OnPK
WE/OffPK
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

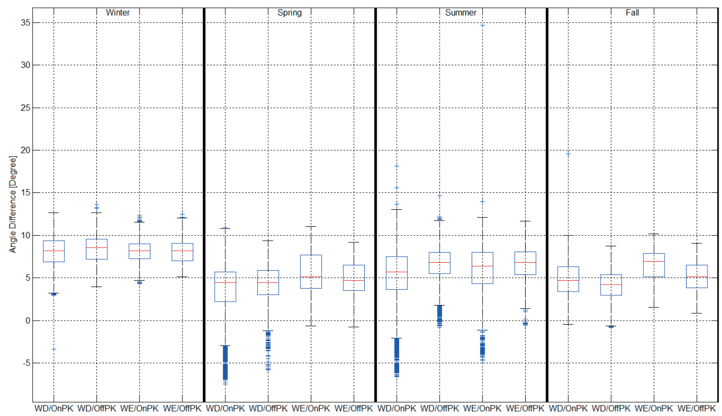
KAMMER2-KEYSTONE 500kV



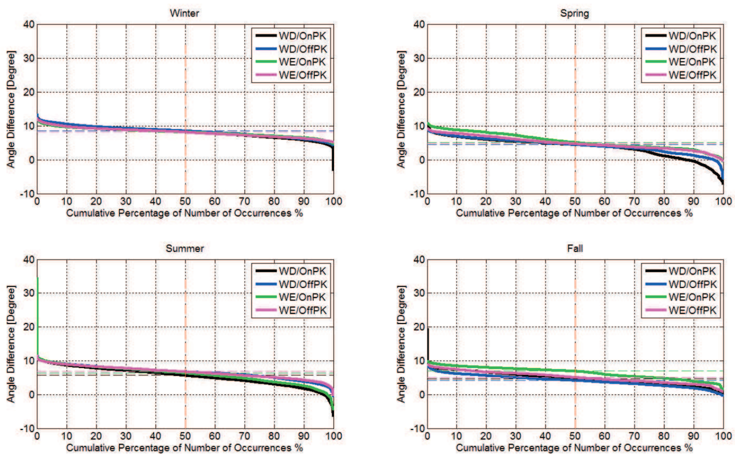
KAMMER2-KEYSTONE 500kV



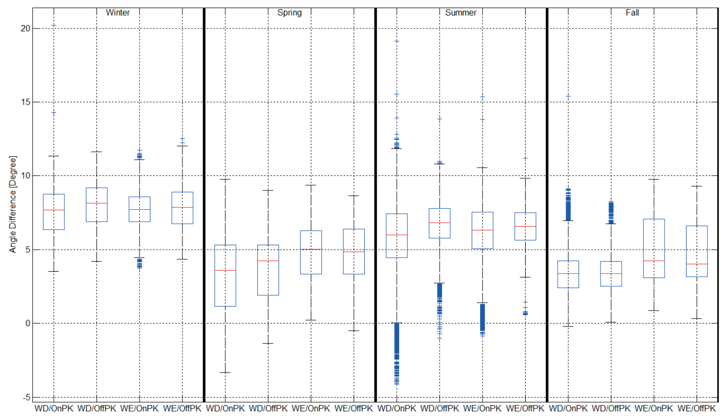
KAMMER2-HATFIELD 500kV



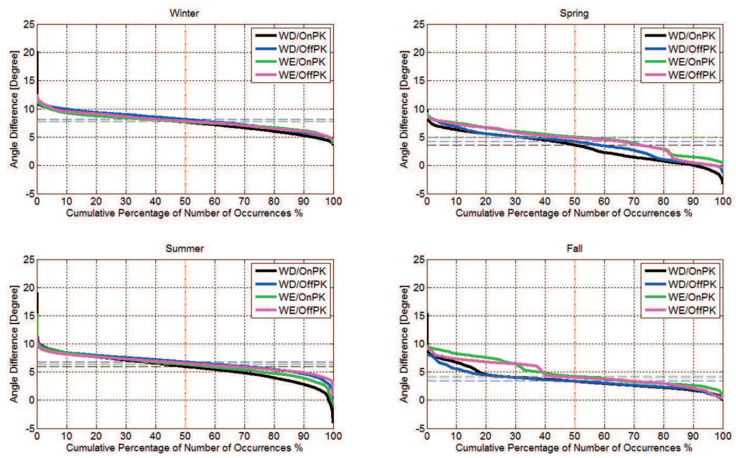
KAMMER2-HATFIELD 500kV



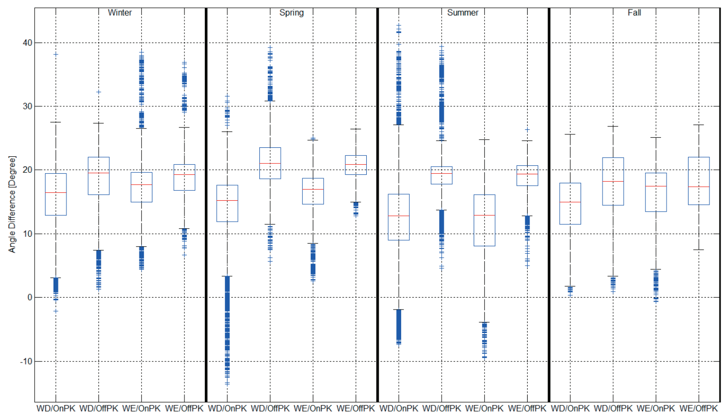
KAMMER2-PRUNTYTO 500kV



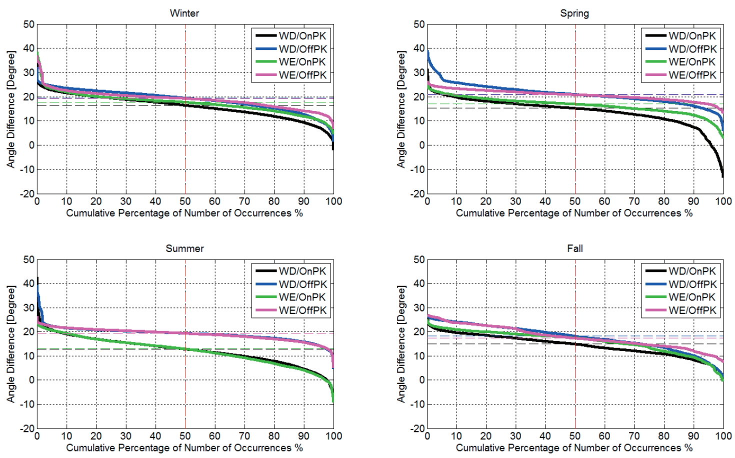
KAMMER2-PRUNTYTO 500kV



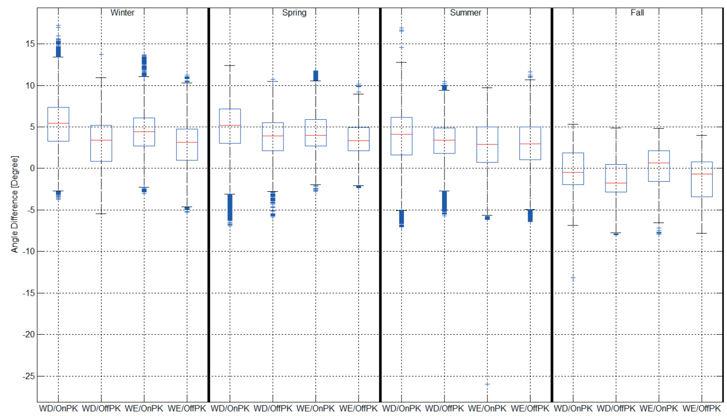
JACKSONS-LEXINGTN 500kV



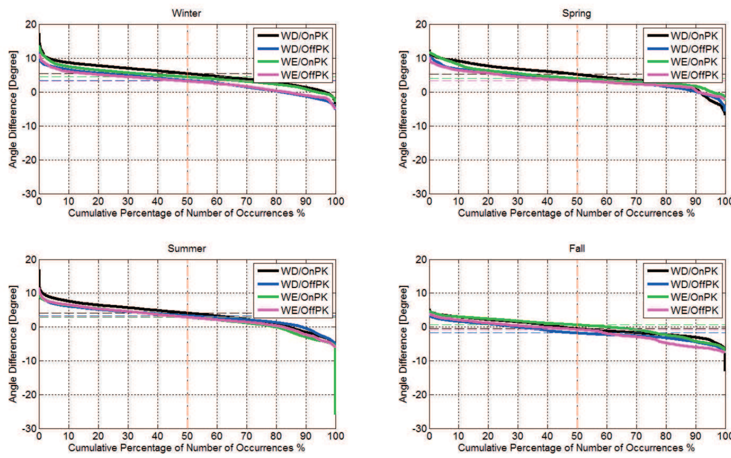
JACKSONS-LEXINGTN 500kV



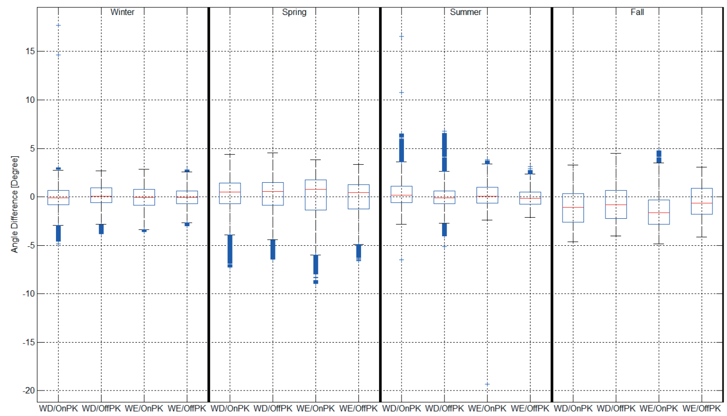
HATFIELD-KEYSTONE 500kV



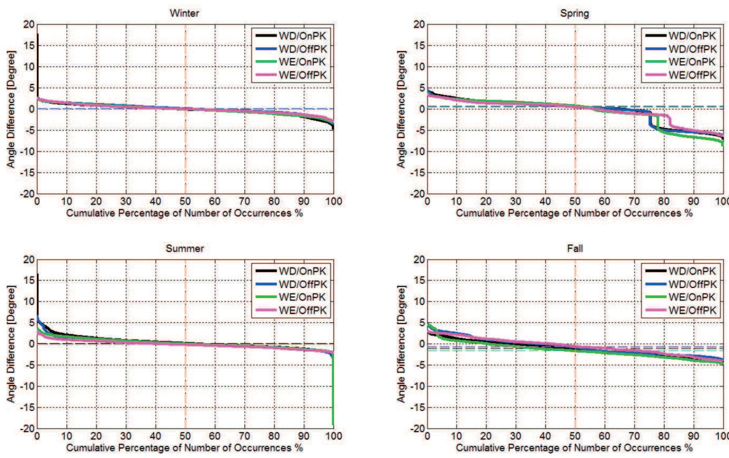
HATFIELD-KEYSTONE 500kV



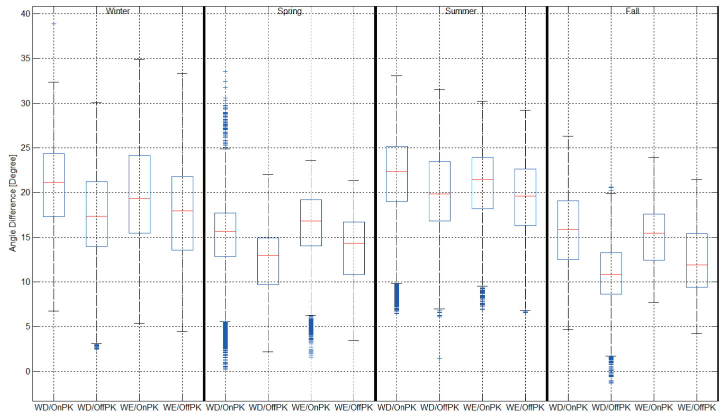
HATFIELD-PRUNTYTO 500kV



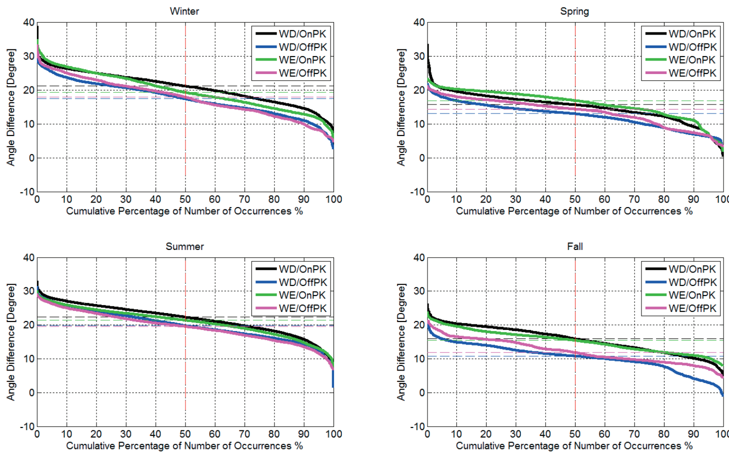
HATFIELD-PRUNTYTO 500kV



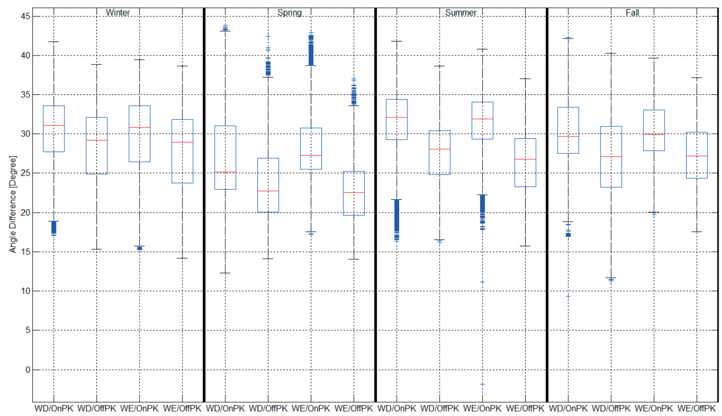
KEYSTONE-JUNIATA 500kV



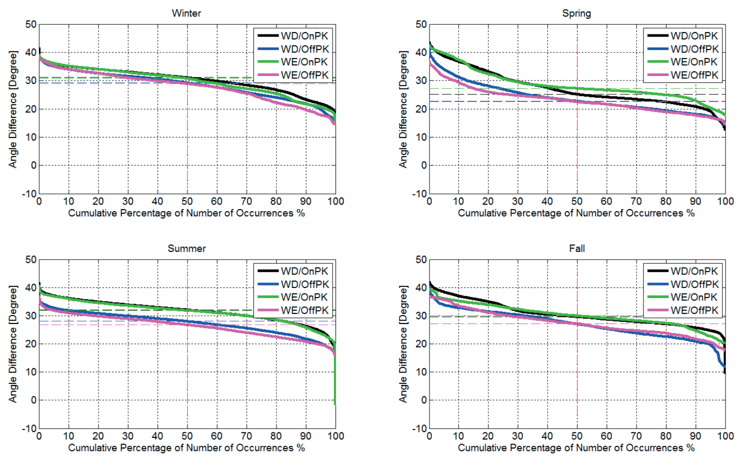
KEYSTONE-JUNIATA 500kV



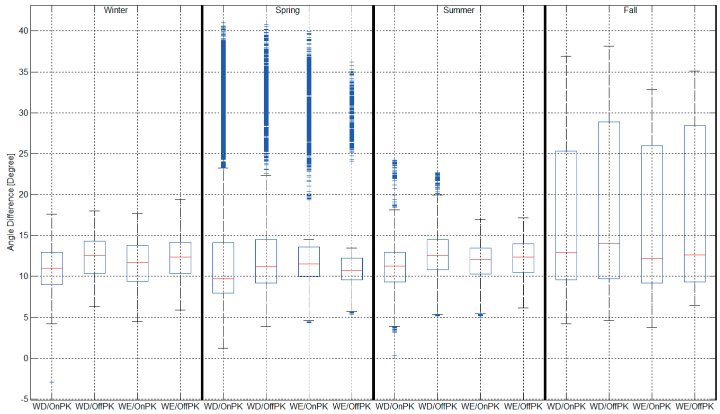
HATFIELD-DOUBS 500kV



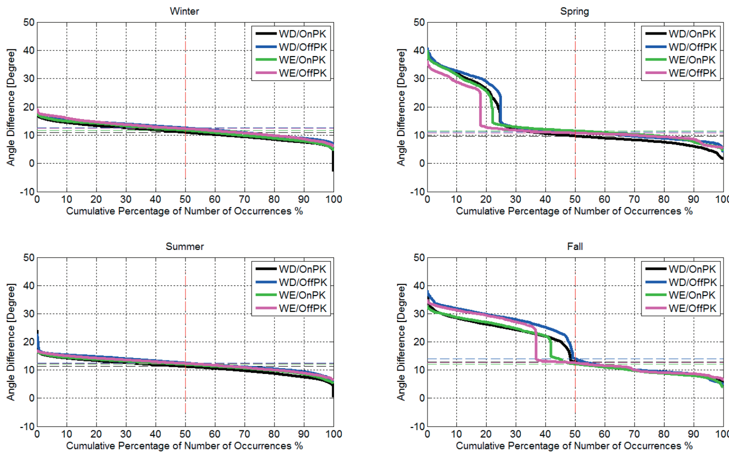
HATFIELD-DOUBS 500kV



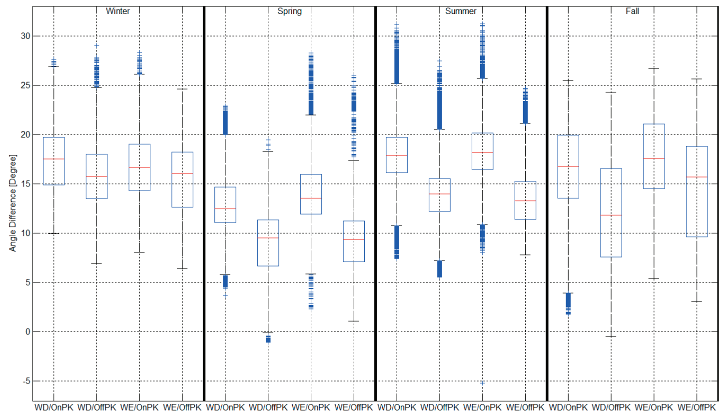
PRUNTYTO-MTSTORM4 500kV



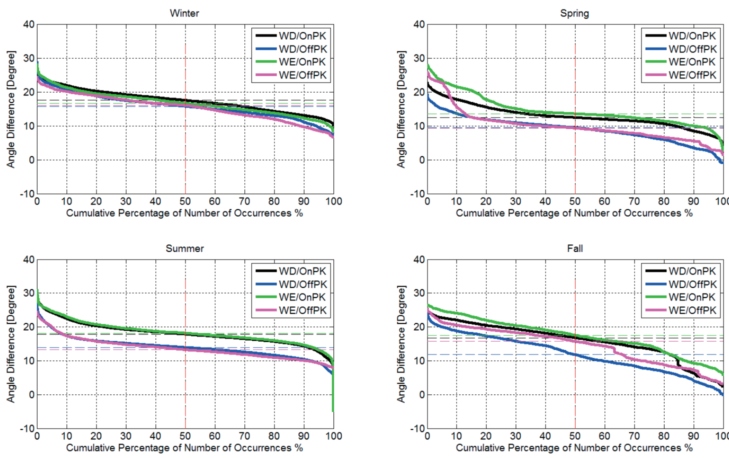
PRUNTYTO-MTSTORM4 500kV



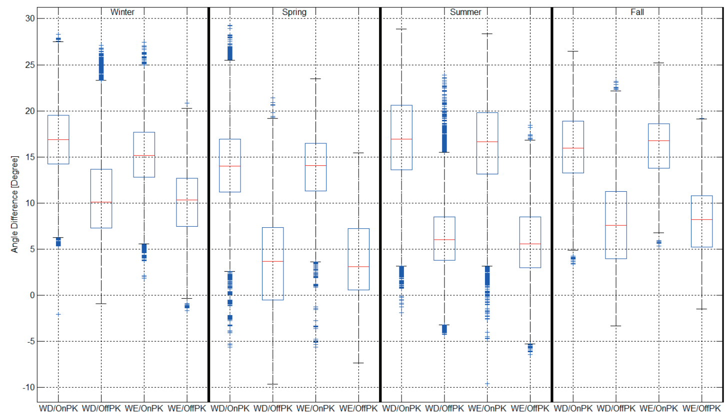
MTSTORM4-MORRISVL 500kV



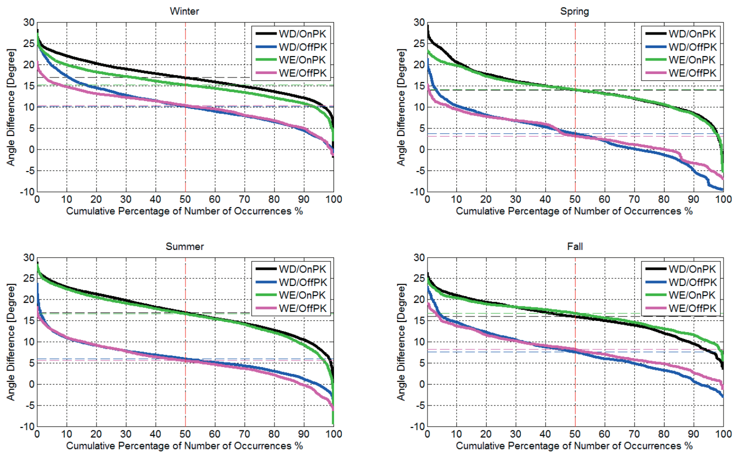
MTSTORM4-MORRISVL 500kV



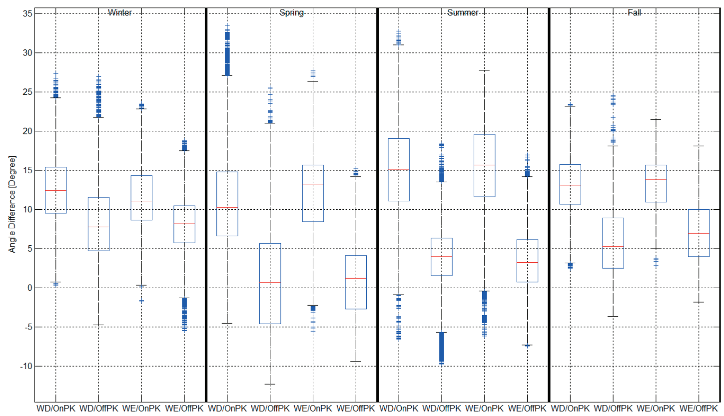
LEXINGTN-MORRISVL 500kV



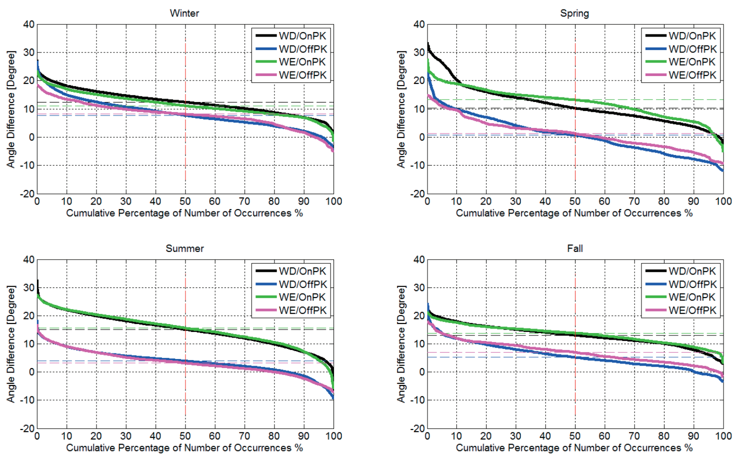
LEXINGTN-MORRISVL 500kV



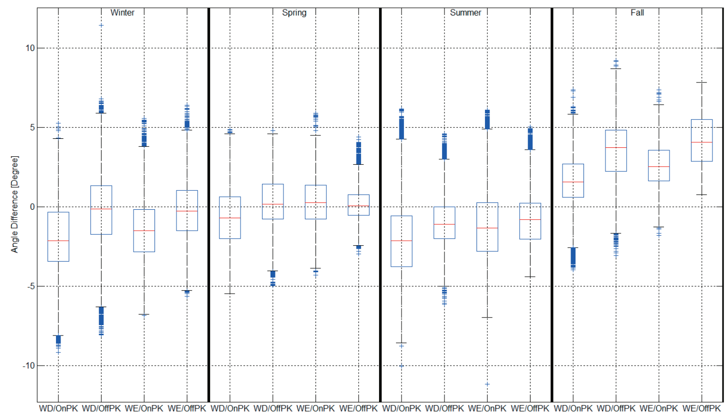
LEXINGTN-SURRY4 500kV



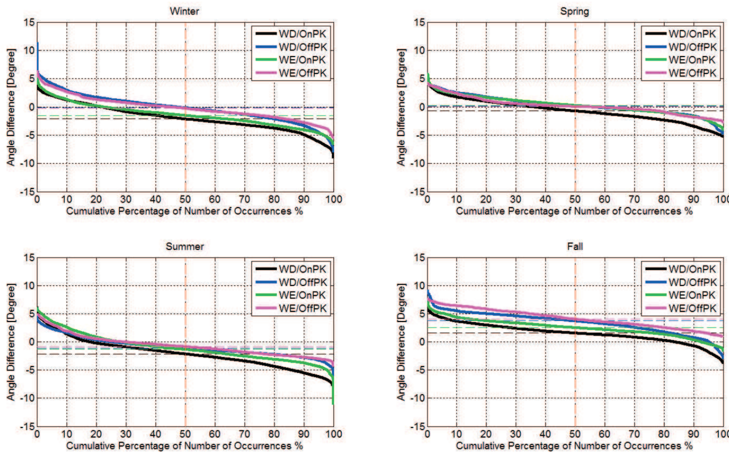
LEXINGTN-SURRY4 500kV



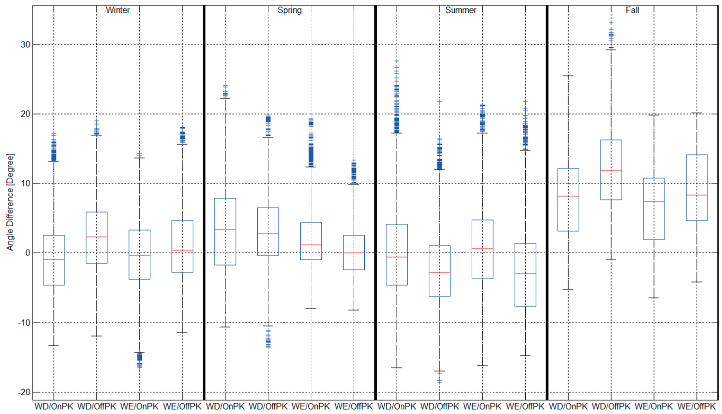
DOUBS-MORRISVL 500kV



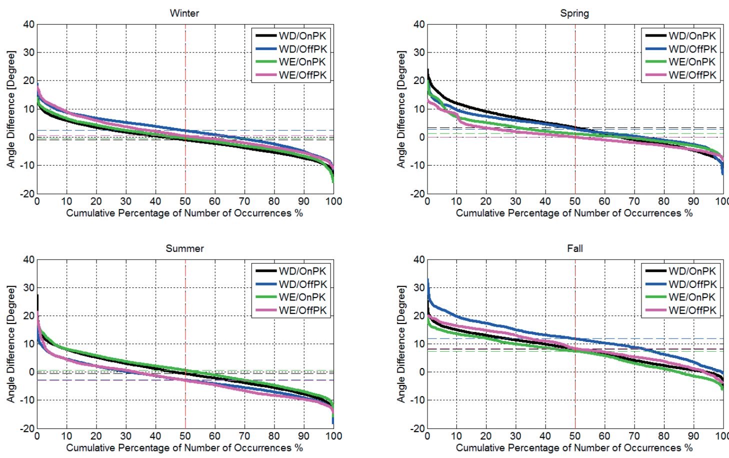
DOUBS-MORRISVL 500kV



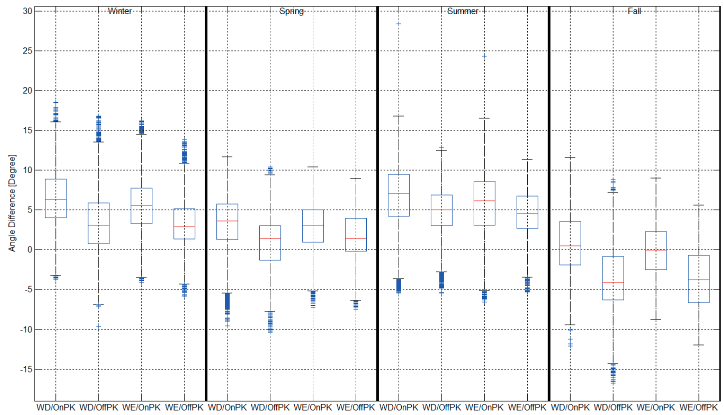
PEACHBOT-DOUBS 500kV



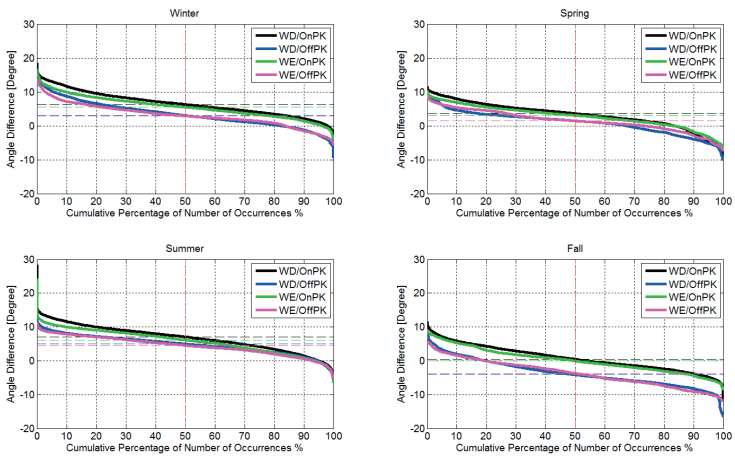
PEACHBOT-DOUBS 500kV



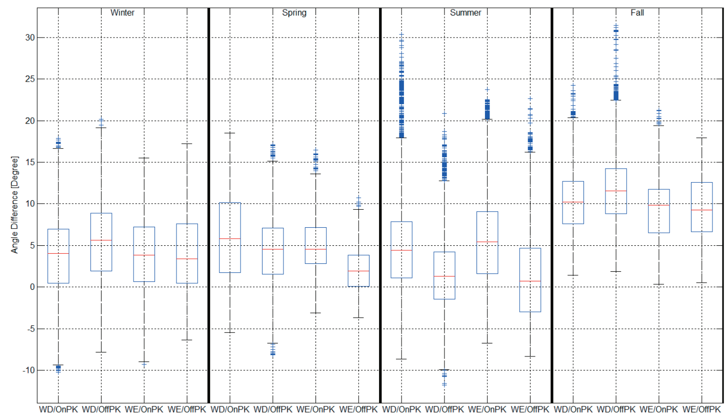
MORRISVL-WAUGHCHA 500kV



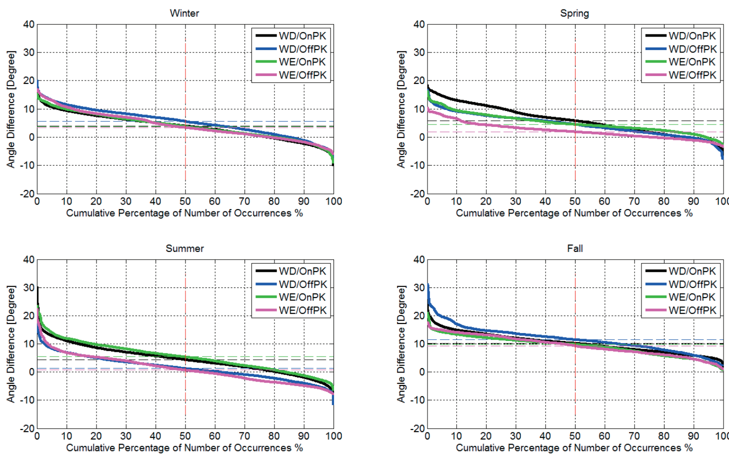
MORRISVL-WAUGHCHA 500kV



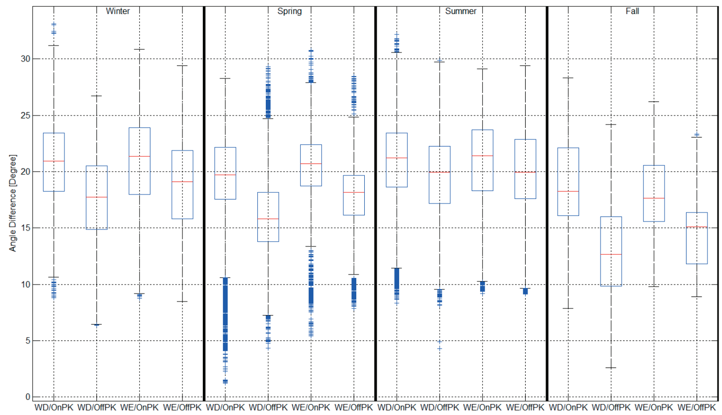
PEACHBOT-WAUGHCHA 500kV



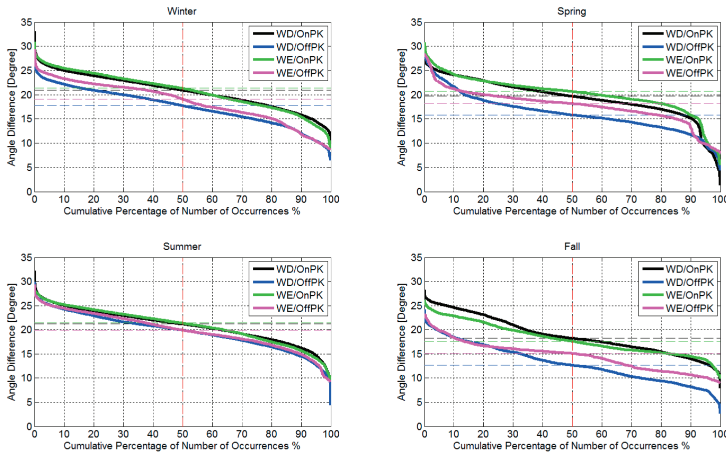
PEACHBOT-WAUGHCHA 500kV

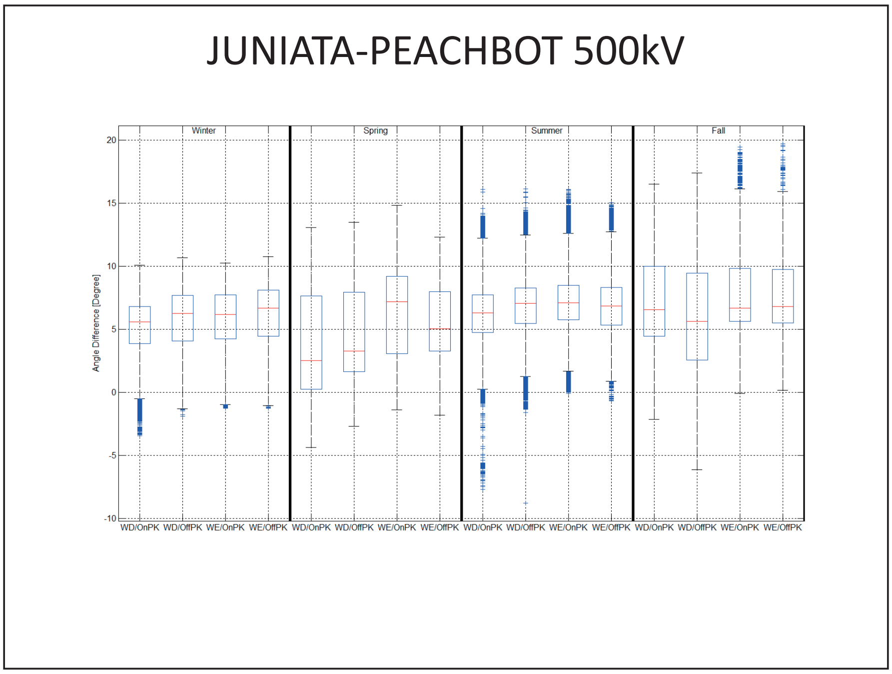


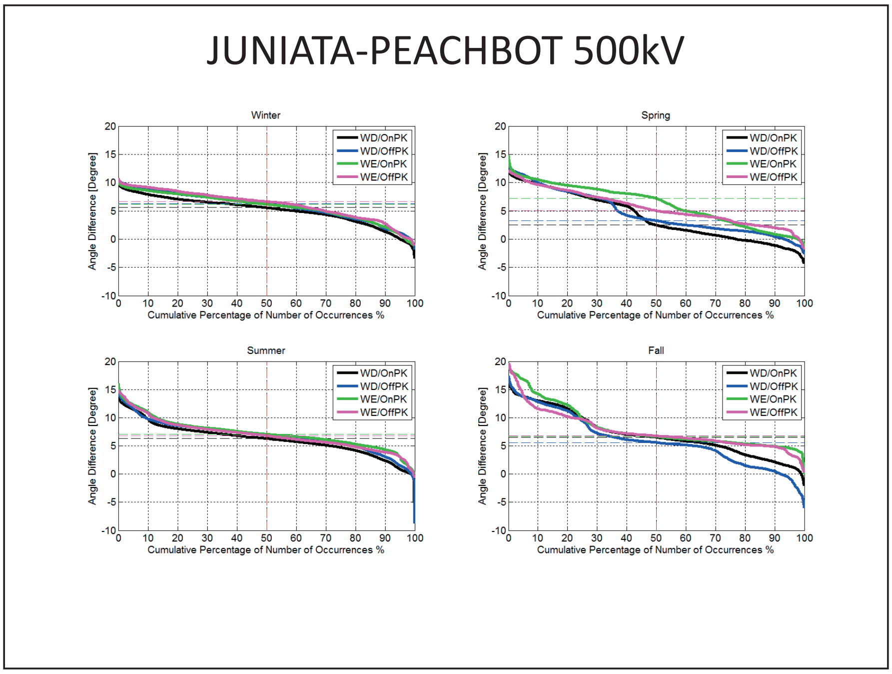
JUNIATA-BRANCHBU 500kV



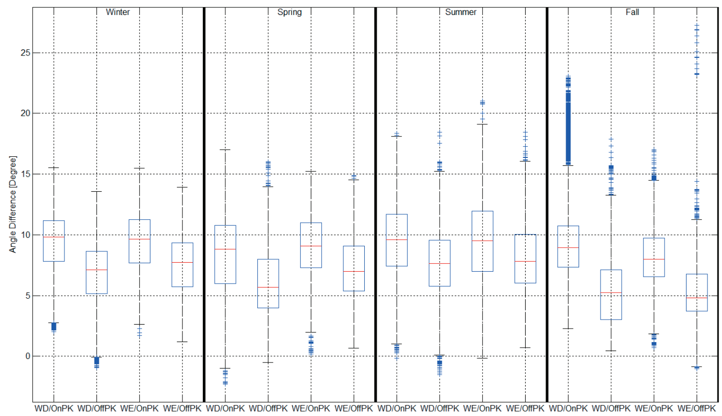
JUNIATA-BRANCHBU 500kV



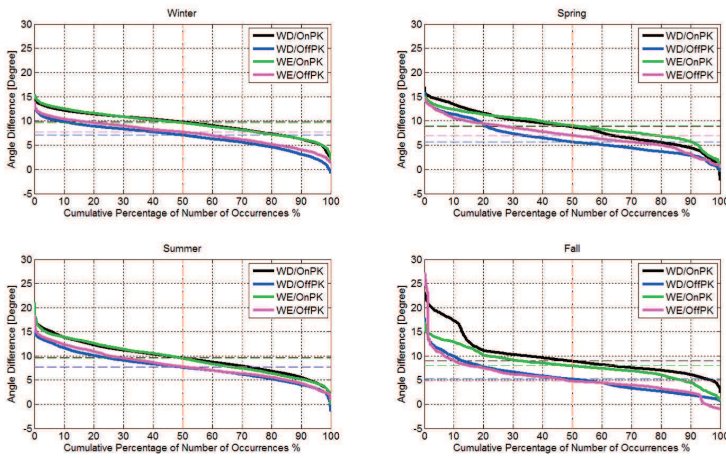

JUNIATA-PEACHBOT 500kV
Winter
Spring
Summer
Fall
Angle Difference [Degree]
WD/OnPK WD/OffPK WE/OnPK WE/OffPK


JUNIATA-PEACHBOT 500kV
Winter
Spring
Summer
Fall
WD/OnPK
WD/OffPK
WE/OnPK
WE/OffPK
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

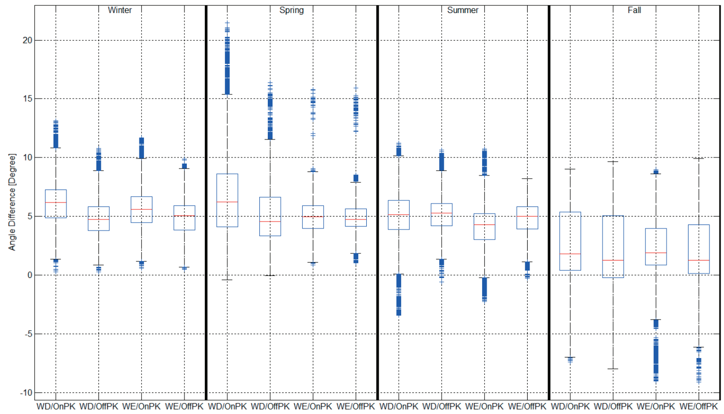
PEACHBOT-NEWFREED 500kV



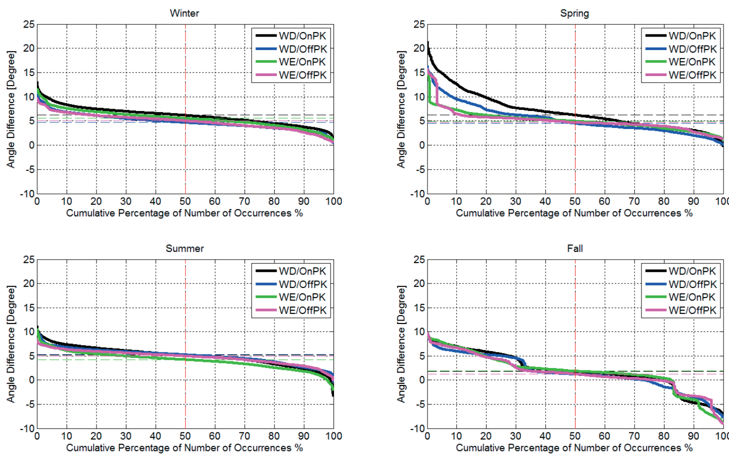
PEACHBOT-NEWFREED 500kV



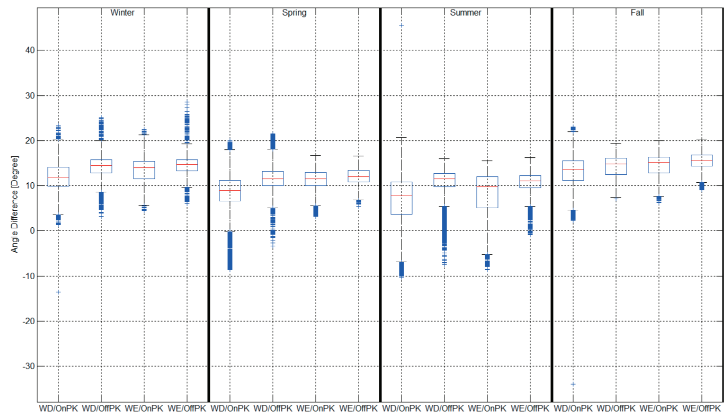
NEWFREED-BRANCHBU 500kV



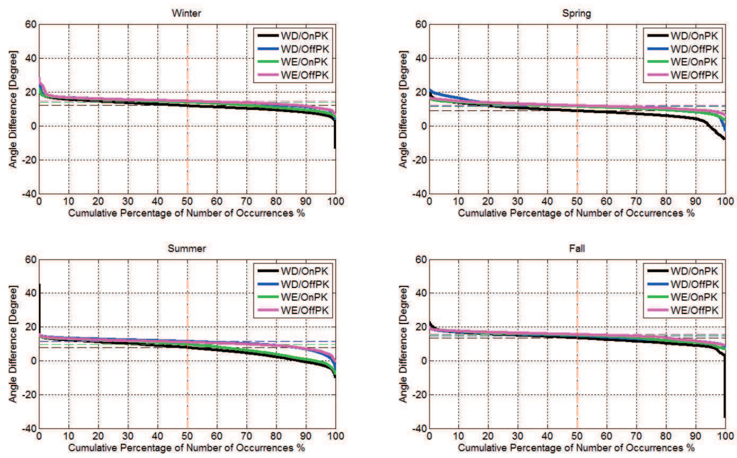
NEWFREED-BRANCHBU 500kV

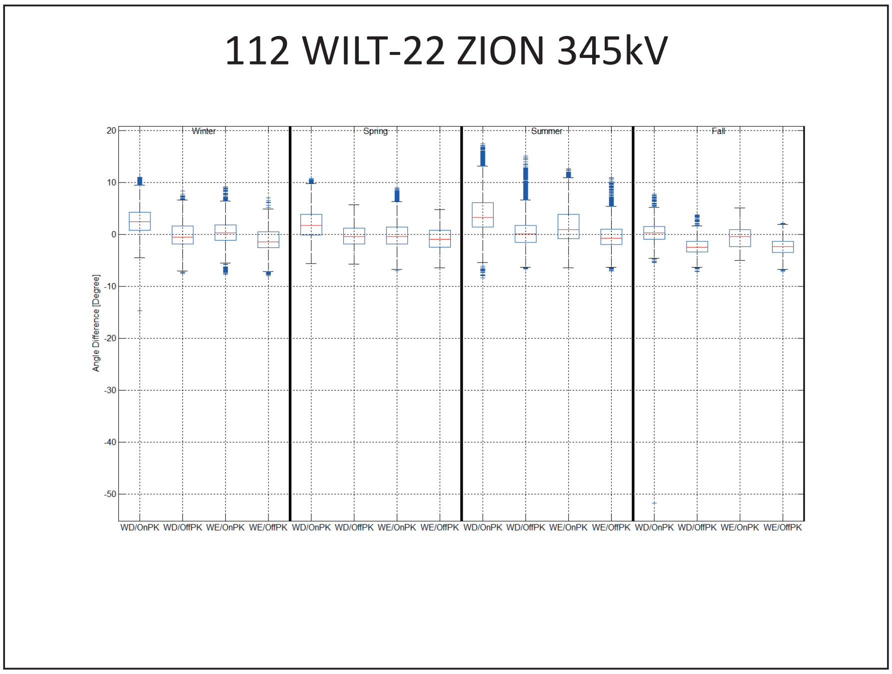


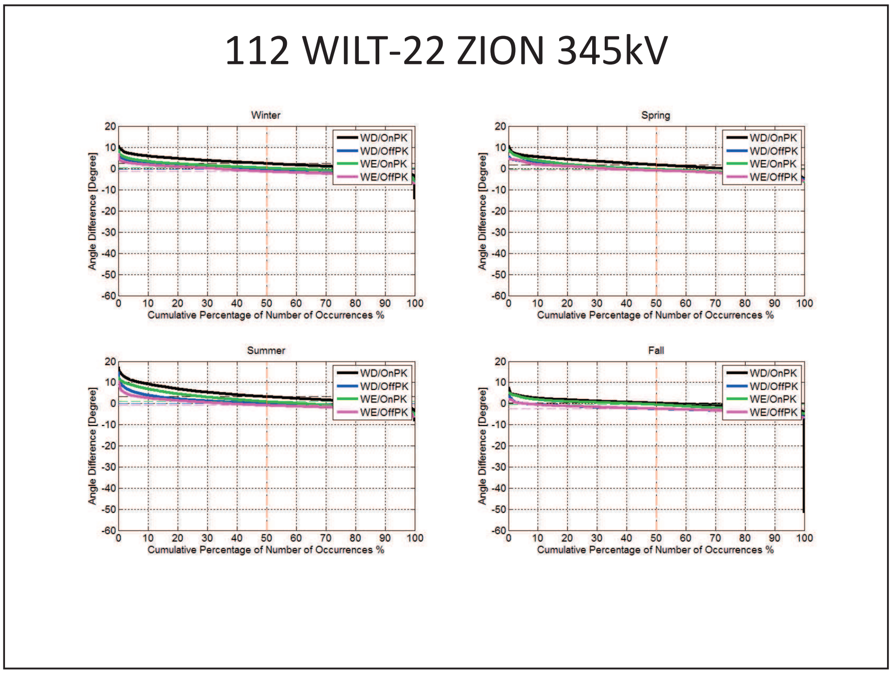
112 WILT-DUMONT2 345kV



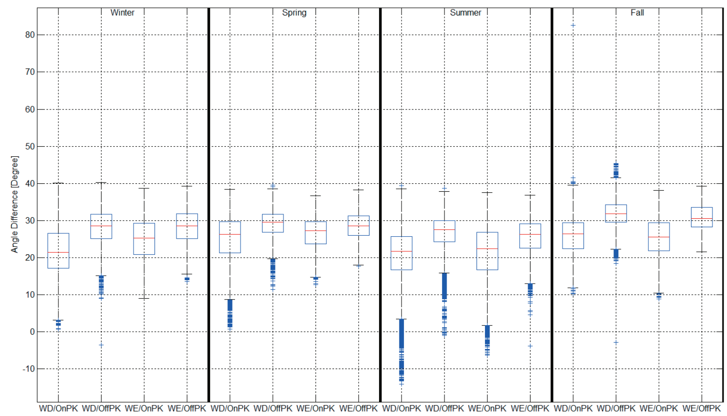
112 WILT-DUMONT2 345kV



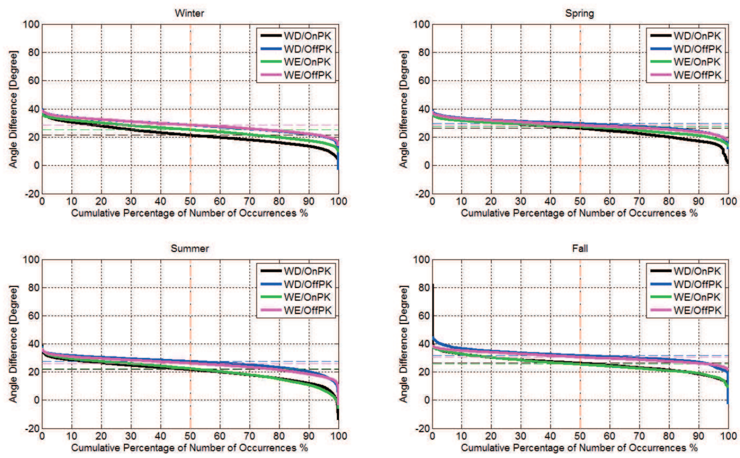

112 WILT-22 ZION 345kV
Winter
Spring
Summer
Fall
Angle Difference [Degree]
WD/OnPK
WD/OffPK
WE/OnPK
WE/OffPK

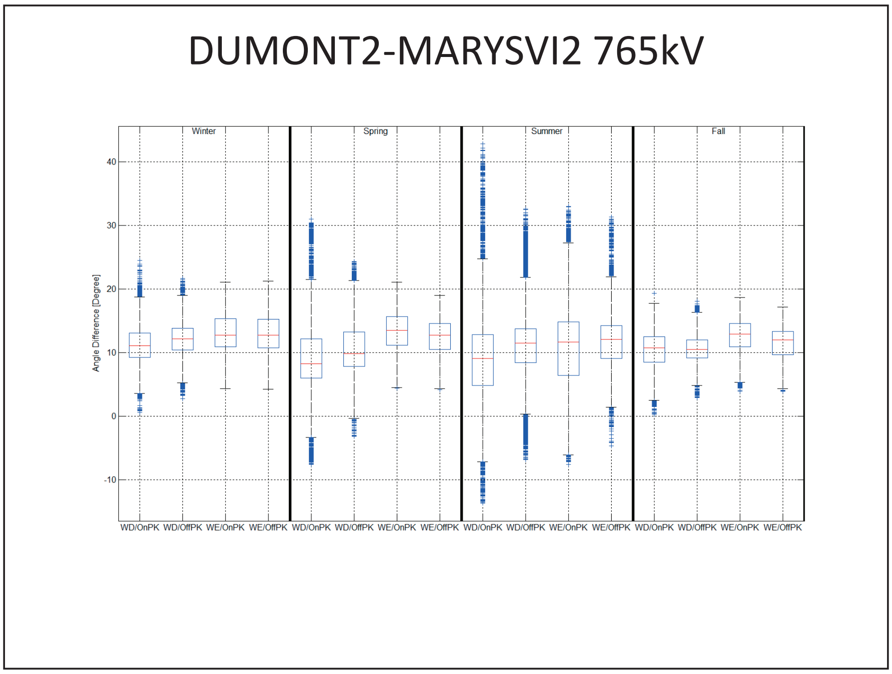

112 WILT-22 ZION 345kV
Winter
Spring
Summer
Fall
WD/OnPK
WD/OffPK
WE/OnPK
WE/OffPK
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

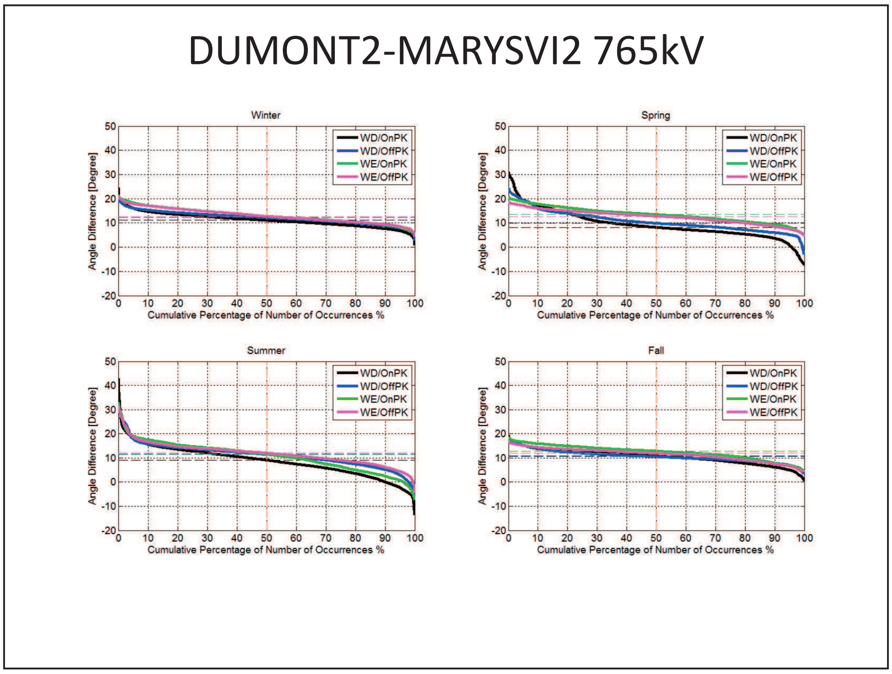
4 QUAD C-112 WILT 345kV

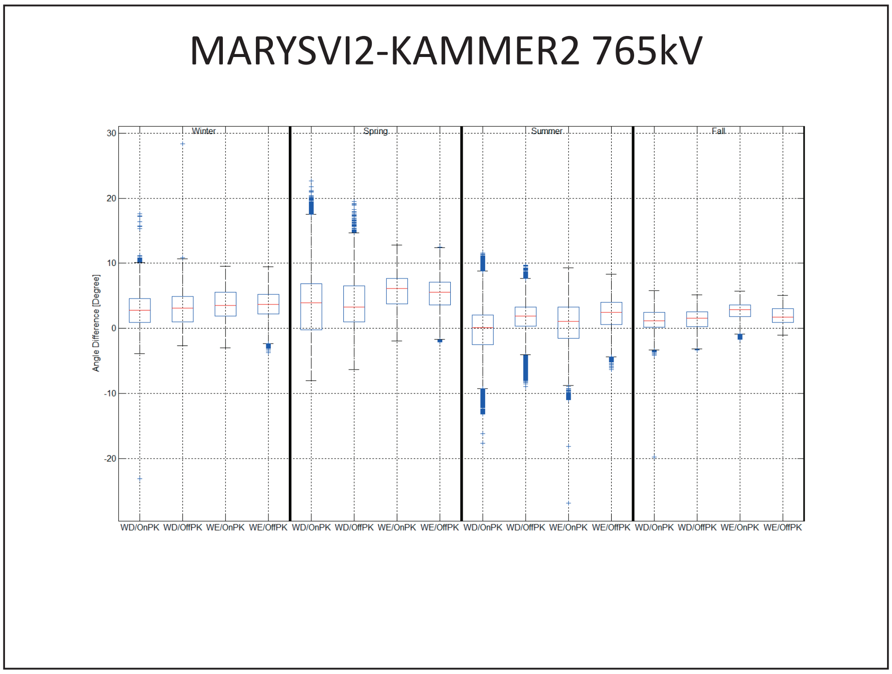


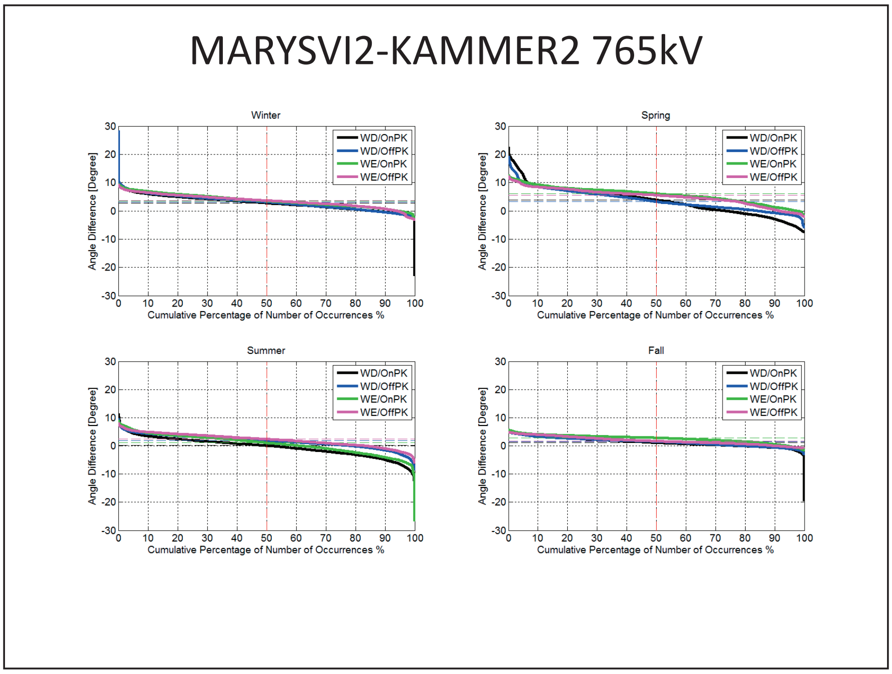
4 QUAD C-112 WILT 345kV



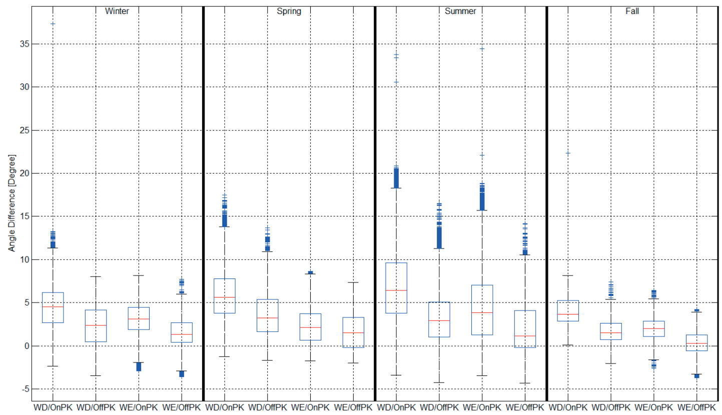

DUMONT2-MARYSVI2 765kV
Winter
Spring
Summer
Fall
Angle Difference [Degree]
WD/OnPK WD/OffPK WE/OnPK WE/OffPK


DUMONT2-MARYSVI2 765kV
Winter
Spring
Summer
Fall
WD/OnPK
WD/OffPK
WE/OnPK
WE/OffPK
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

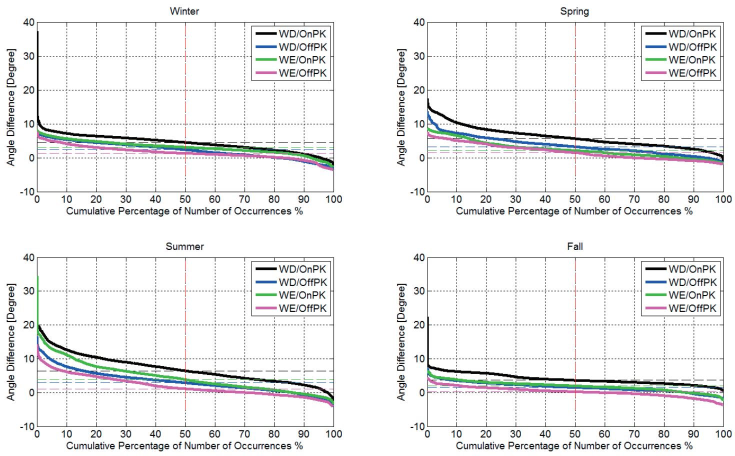

MARYSVI2-KAMMER2 765kV
Winter
Spring
Summer
Fall
Angle Difference [Degree]
WD/OnPK WD/OffPK WE/OnPK WE/OffPK

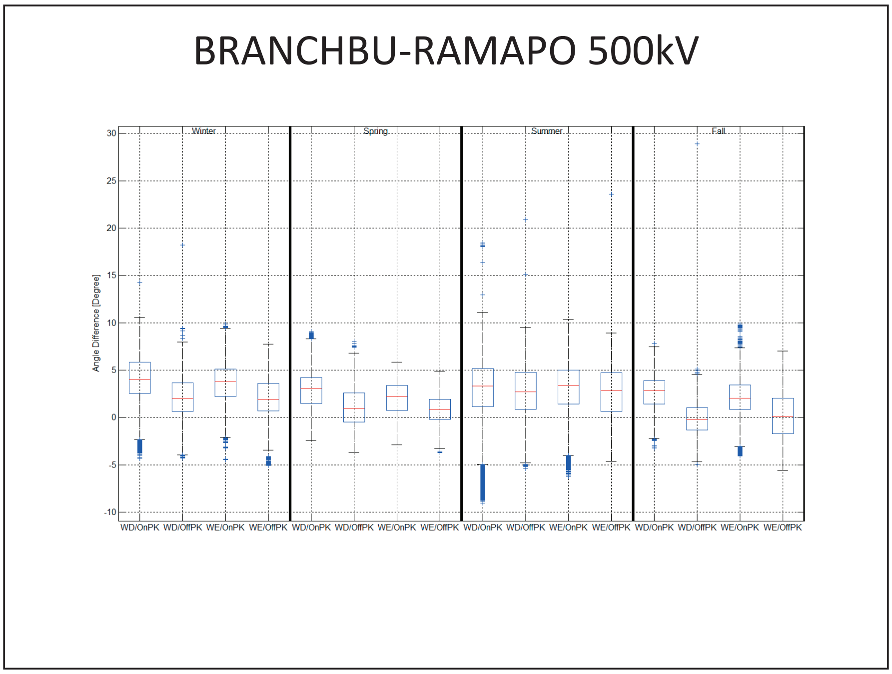

MARYSVI2-KAMMER2 765kV
Winter
Spring
Summer
Fall
WD/OnPK
WD/OffPK
WE/OnPK
WE/OffPK
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

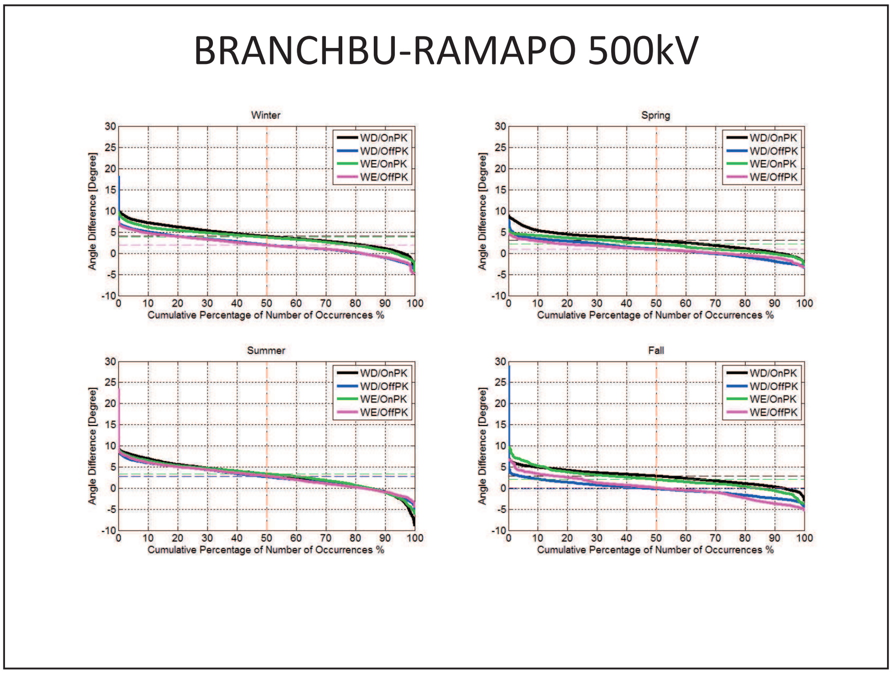
AMOS-MARYSVI2 765kV



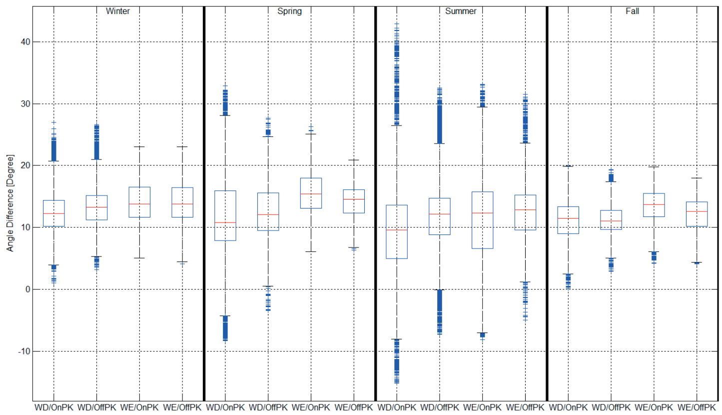
AMOS-MARYSVI2 765kV



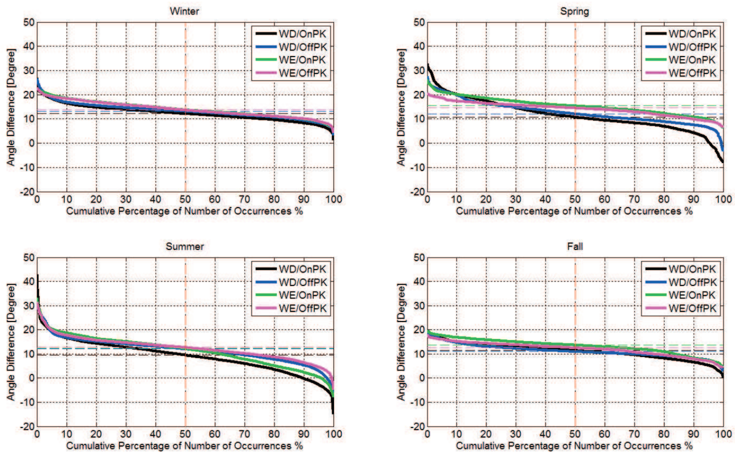

BRANCHBU-RAMAPO 500kV
Winter
Spring
Summer
Fall
Angle Difference [Degree]
WD/OnPK WD/OffPK WE/OnPK WE/OffPK


BRANCHBU-RAMAPO 500kV
Winter
Spring
Summer
Fall
WD/OnPK
WD/OffPK
WE/OnPK
WE/OffPK
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %

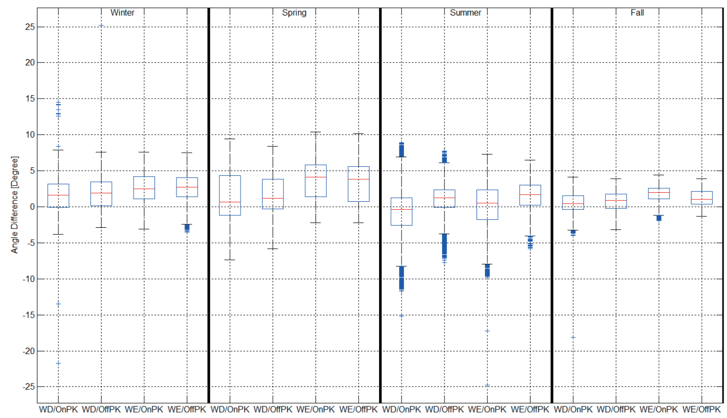
DUMONT2-MALISZEW 765kV



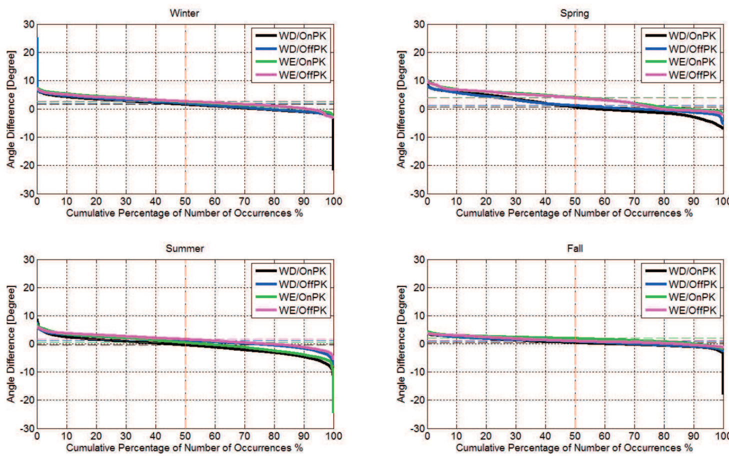
DUMONT2-MALISZEW 765kV



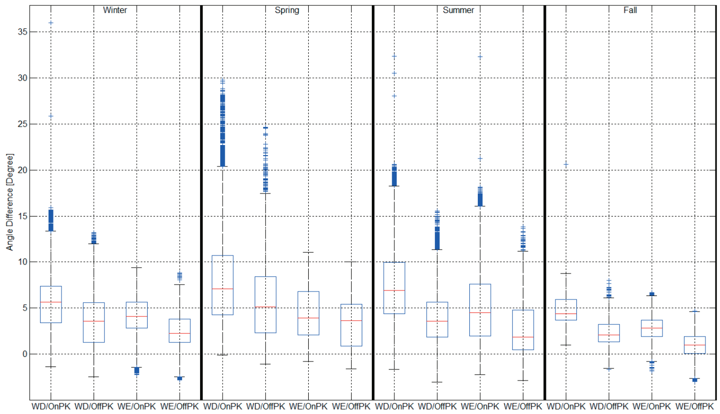
MALISZEW-KAMMER2 765kV



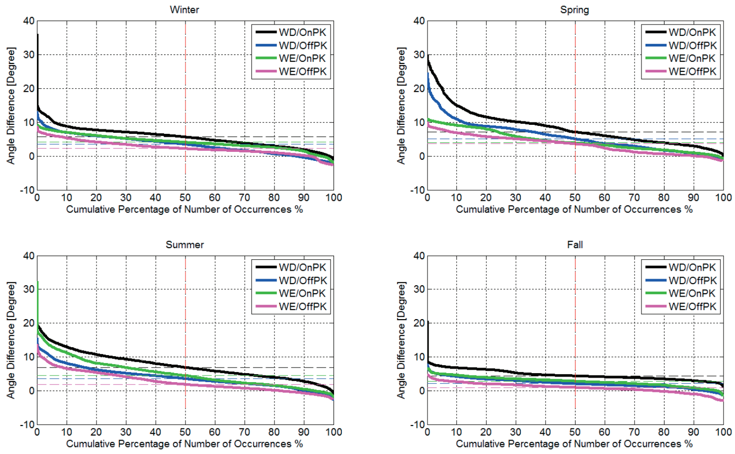
MALISZEW-KAMMER2 765kV



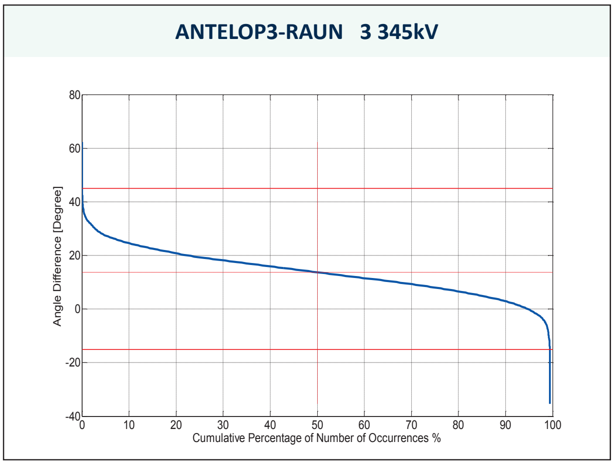
AMOS-MALISZEW 765kV

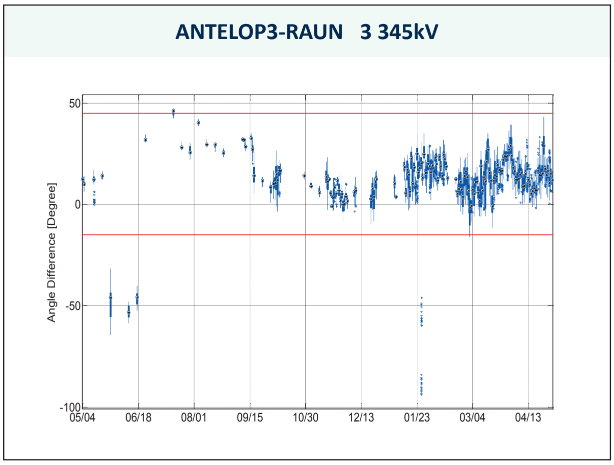


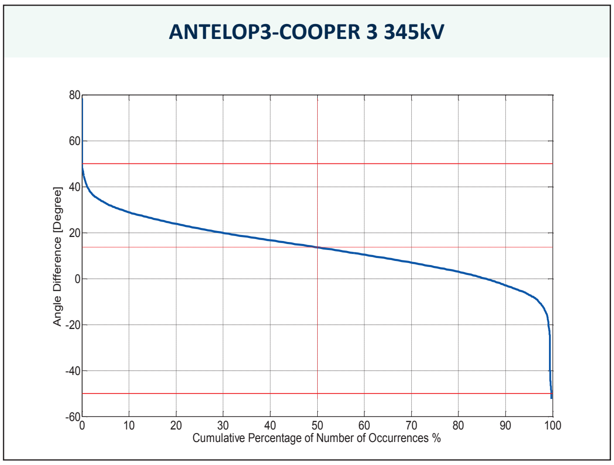
AMOS-MALISZEW 765kV

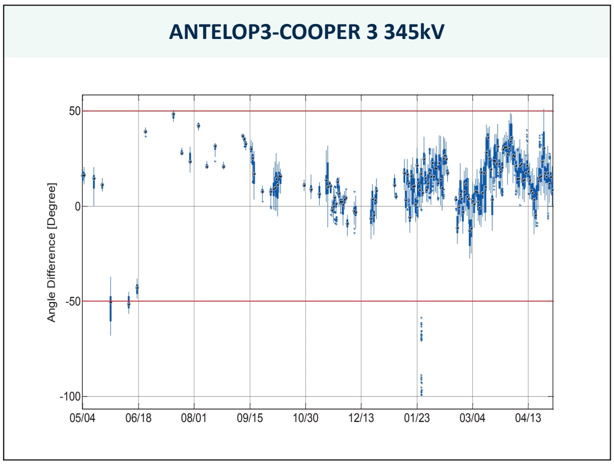


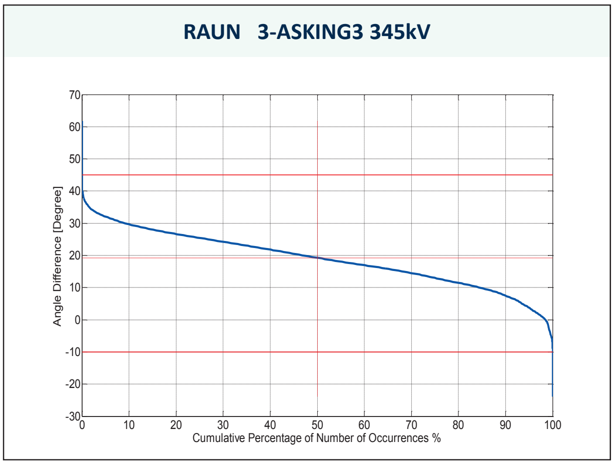
A.3 MISO Selected Angle Pairs Box Whisker Plots and Time Duration Plots

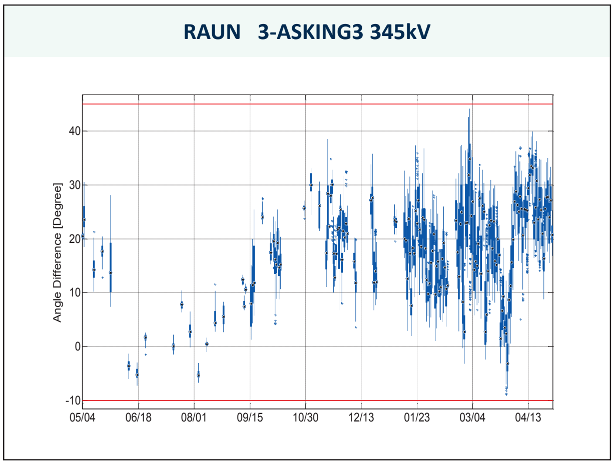


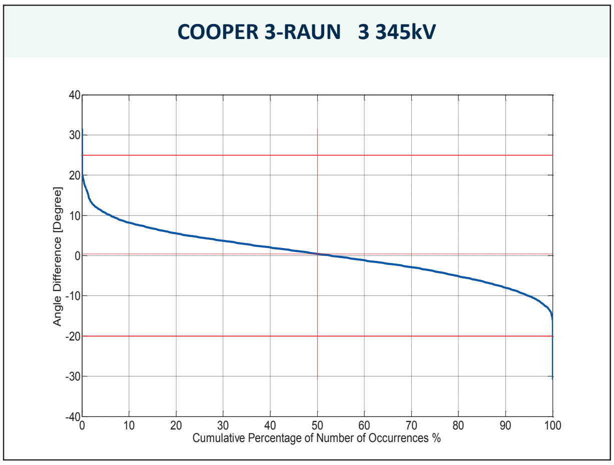


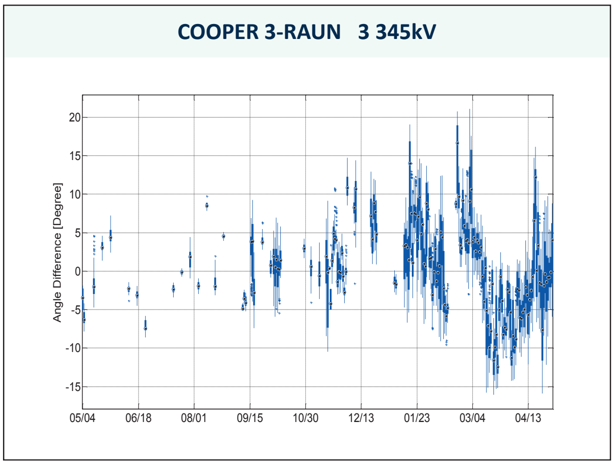




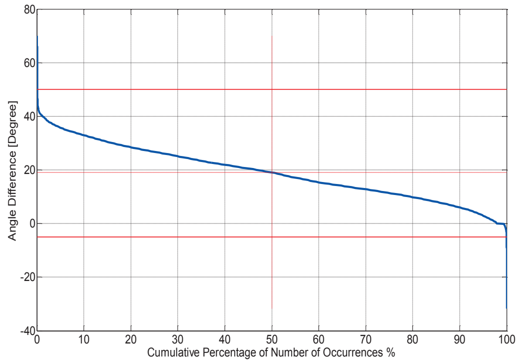

RAUN 3-ASKING3 345kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


RAUN 3-ASKING3 345kV
Angle Difference [Degree]
05/04 06/18 08/01 09/15 10/30 12/13 01/23 03/04 04/13

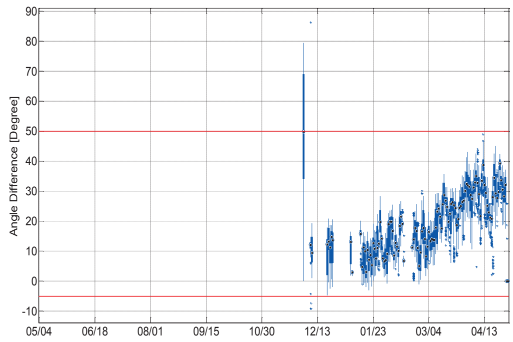

COOPER 3-RAUN 3 345kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


COOPER 3-RAUN 3 345kV
Angle Difference [Degree]
05/04 06/18 08/01 09/15 10/30 12/13 01/23 03/04 04/13

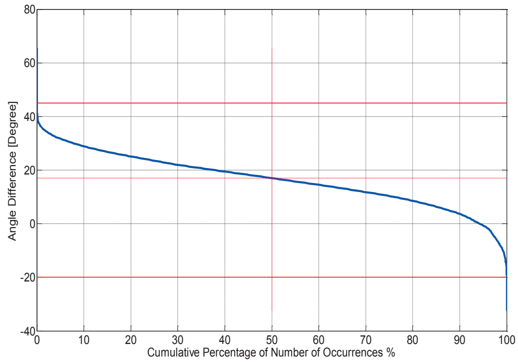
DORSEY 2-CHIS_CO 500kV



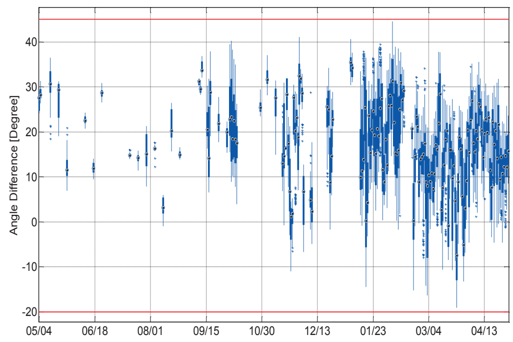
DORSEY 2-CHIS_CO 500kV



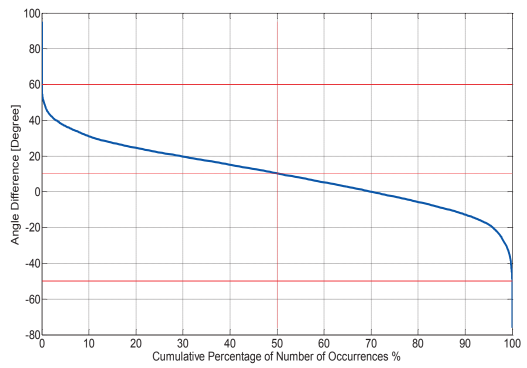
COOPER 3-CALAWY 1 345kV



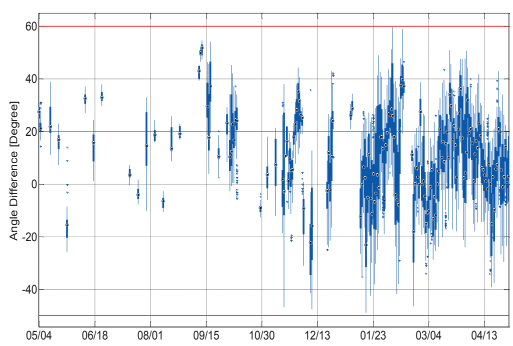
COOPER 3-CALAWY 1 345kV



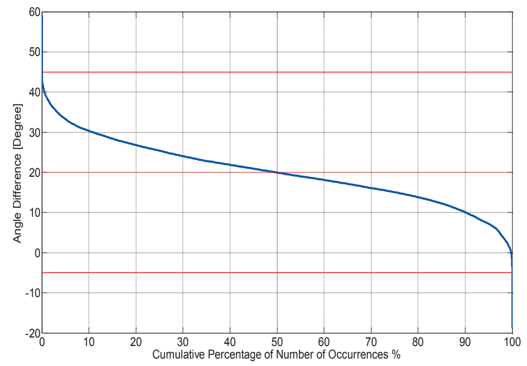
ASKING3-ARCADIA7 345kV



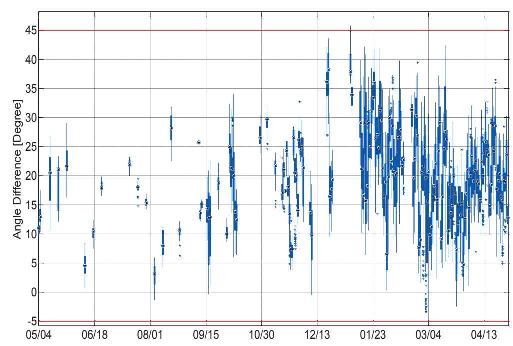
ASKING3-ARCADIA7 345kV



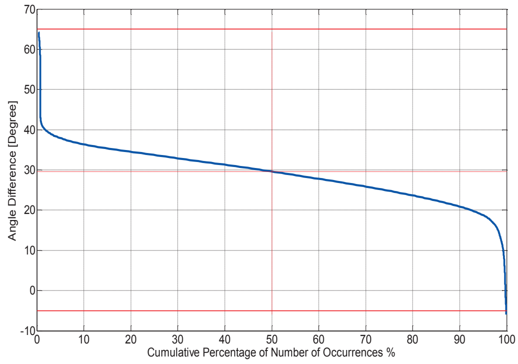
COOPER 3-QUAD ; 345kV



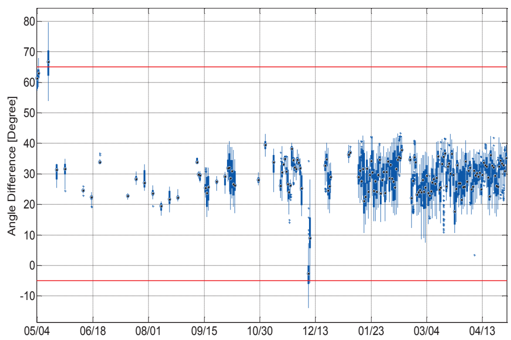
COOPER 3-QUAD ; 345kV



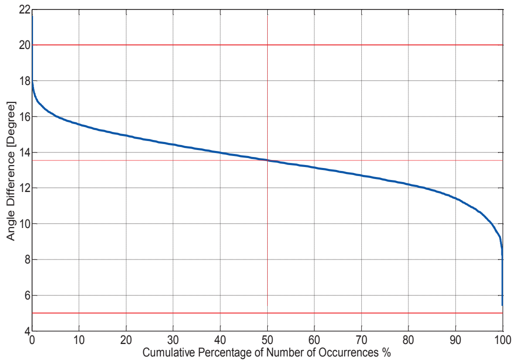
QUAD ;-TAYLOR 345kV



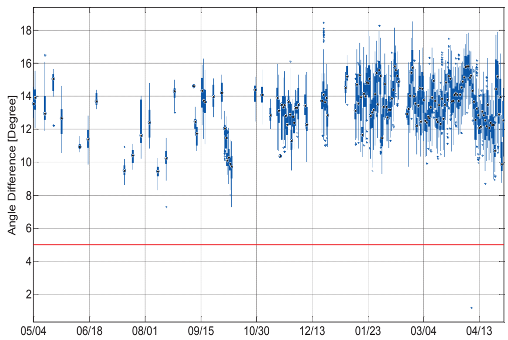
QUAD ;-TAYLOR 345kV

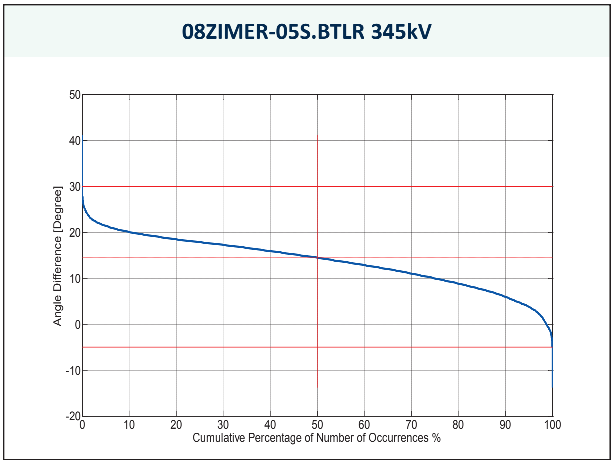


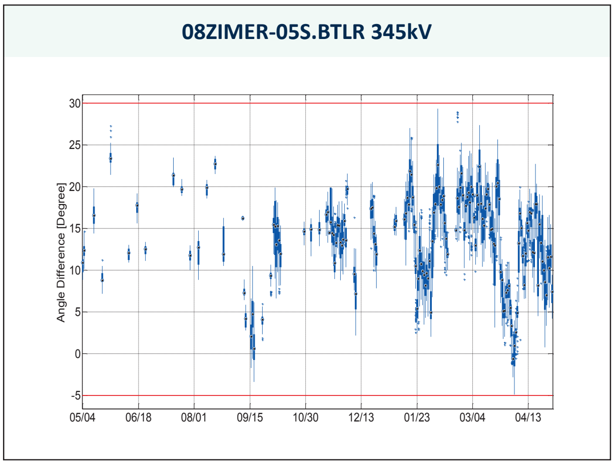
05DUMONT-05S.BTLR 345kV

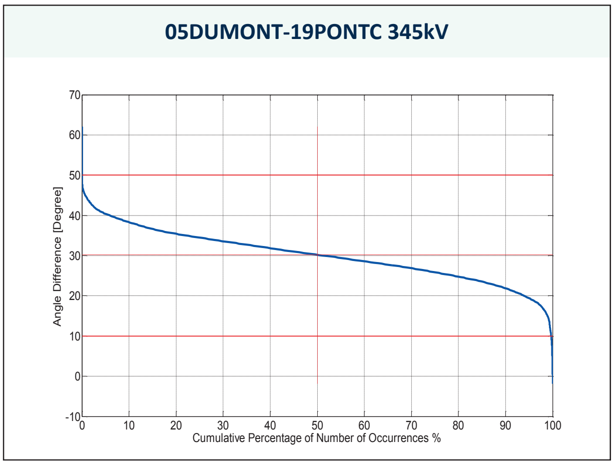


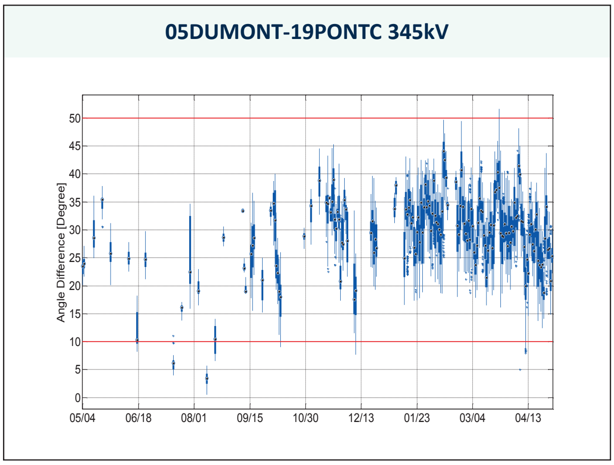
05DUMONT-05S.BTLR 345kV



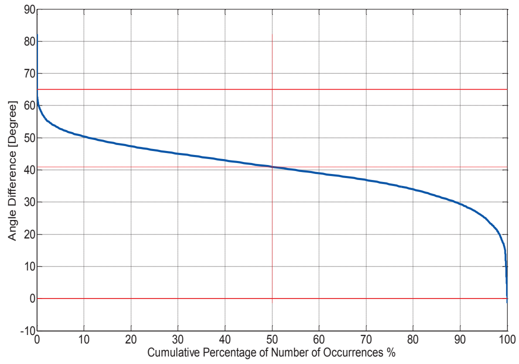

08ZIMER-05S.BTLR 345kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


08ZIMER-05S.BTLR 345kV
Angle Difference [Degree]

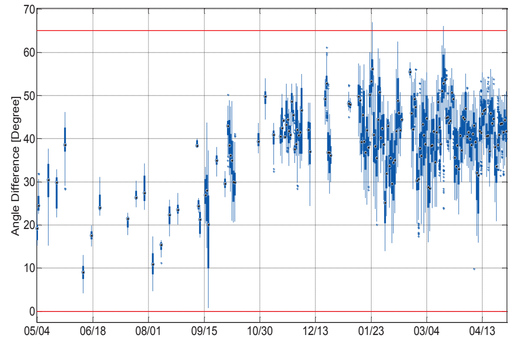

05DUMONT-19PONTC 345kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


05DUMONT-19PONTC 345kV
Angle Difference [Degree]

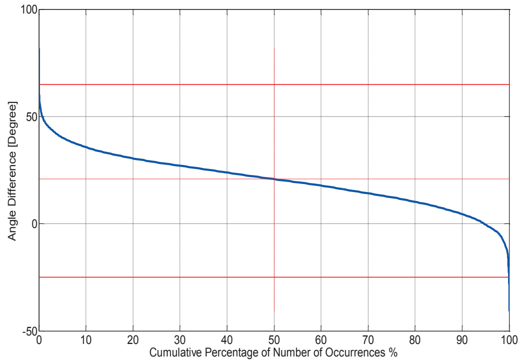
CALAWY 1-05DUMONT 345kV



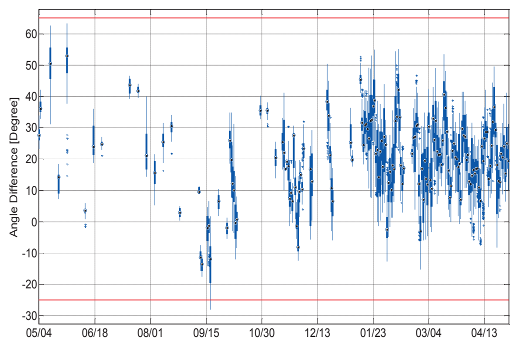
CALAWY 1-05DUMONT 345kV

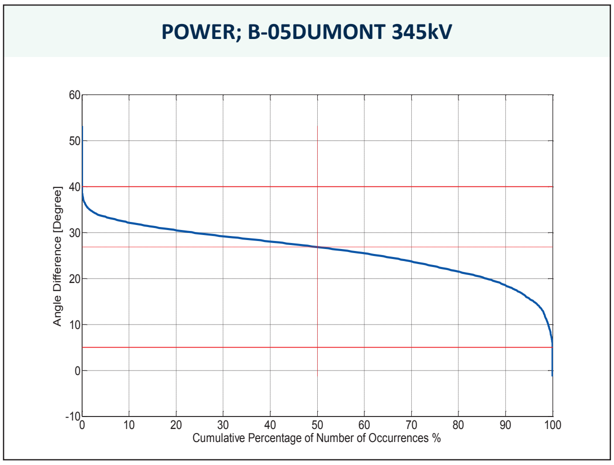


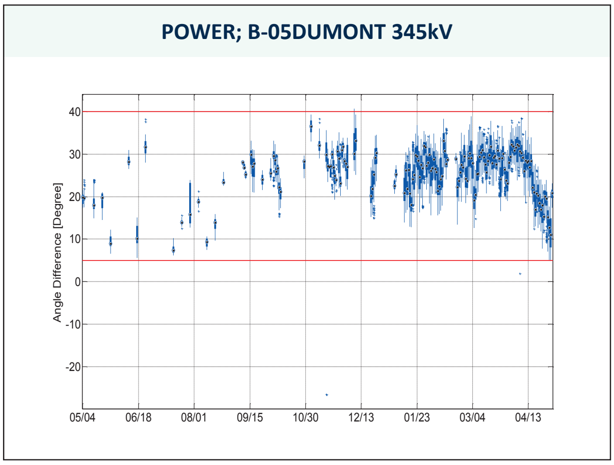
ARCADIA7-TAYLOR 345kV

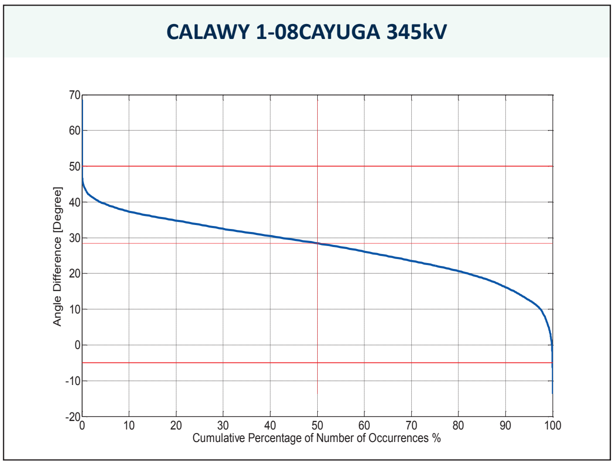


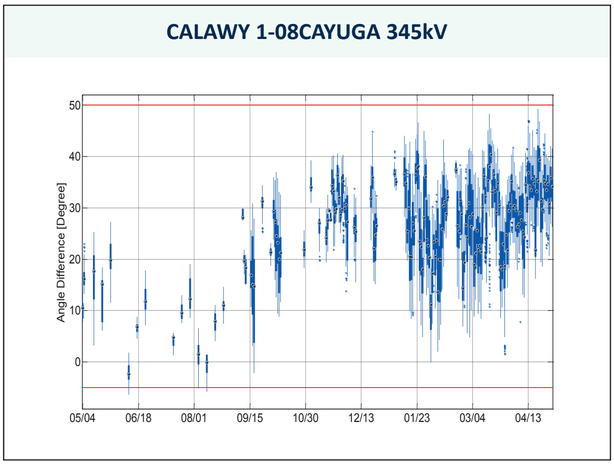
ARCADIA7-TAYLOR 345kV



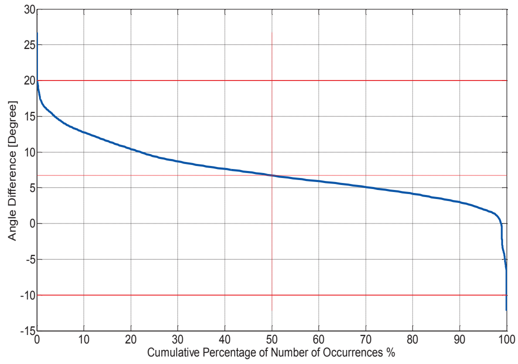

POWER; B-05DUMONT 345kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


POWER; B-05DUMONT 345kV
Angle Difference [Degree]
05/04 06/18 08/01 09/15 10/30 12/13 01/23 03/04 04/13

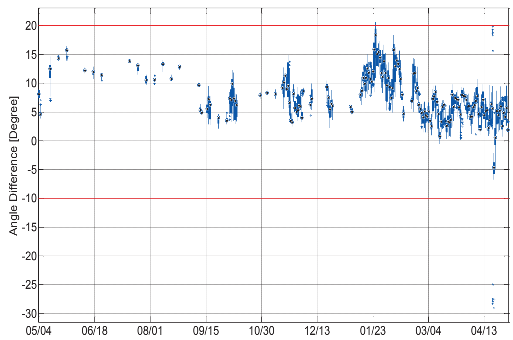

CALAWY 1-08CAYUGA 345kV
Angle Difference [Degree]
Cumulative Percentage of Number of Occurrences %


CALAWY 1-08CAYUGA 345kV
Angle Difference [Degree]
05/04 06/18 08/01 09/15 10/30 12/13 01/23 03/04 04/13

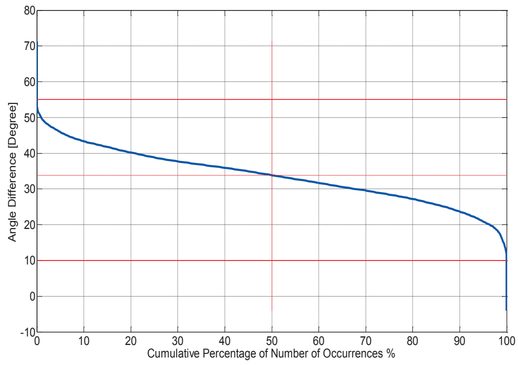
08GIBSON-08CAYUGA 345kV



08GIBSON-08CAYUGA 345kV



08GIBSON-05S.BTLR 345kV



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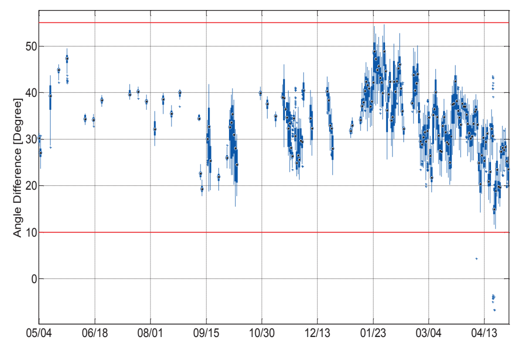
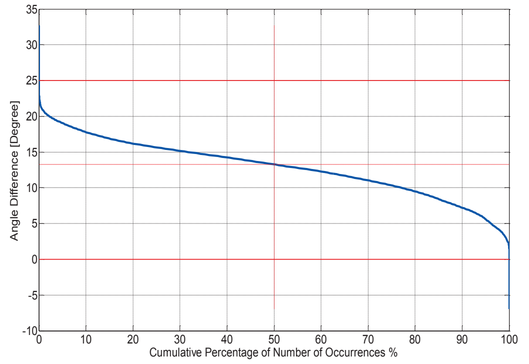
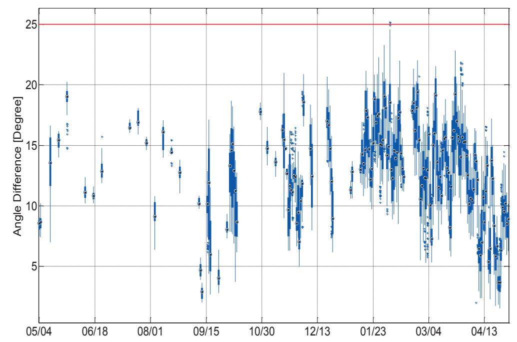


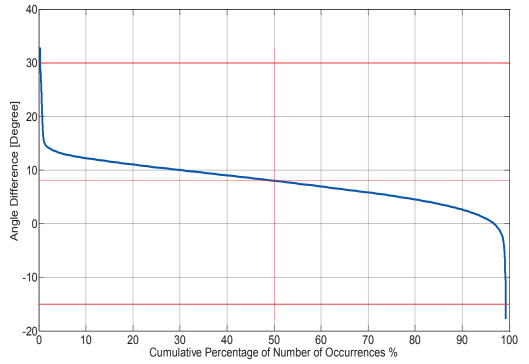
08CAYUGA-05DUMONT 345kV



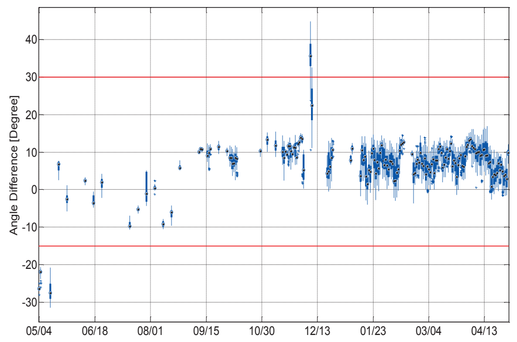
08CAYUGA-05DUMONT 345kV



TAYLOR-05DUMONT 345kV



TAYLOR-05DUMONT 345kV



A.4 MISO Outlier Events List

Index	Date of Outlier	Affected Bus	Voltage Level (kV)	Cause of Outlier	Potential Cause
1	5/5/2010	FTTHOMP	345	VM drop below 350kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage fluctuation was believed to be due to change in loading of FTTHOMP 345 kV bus.
2	5/12/2010	FTTHOMP	345	VM drop below 350kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage fluctuation was believed to be due to change in loading of FTTHOMP 345 kV bus.
3	5/26/2010	FTTHOMP	345	VM drop to 349	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage fluctuation was believed to be due to change in loading of FTTHOMP 345 kV bus.
4	6/16/2010	FTTHOMP	345	VM drop below 350kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage remained below 350 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified
5	6/23/2010	HAZLTON	345	VM drop to 342kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 342 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
6	7/21/2010	HURON 3	345	VM drop to 341.5kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage fluctuation was believed to be due to the Shunt Capacitor operation.
7	10/10/2010	02GALION	345	VM rise to 355kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 342 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
8	11/21/2010	11PINEV	500	VM drop to 565kV	The outage of 11PINEV-11POCKET 500 kV line was identified to be the cause for the voltage rise at 11PINEV 500 kV bus. The high mismatch values also indicate that the flows may not be genuine.
9	11/26/2010	11PINEV	500	VM drop to 570kV	The outage of 11PINEV-11POCKET 500 kV line was identified to be the cause for the voltage rise at 11PINEV 500 kV bus. The high mismatch values also indicate that the flows may not be genuine.
10	11/26/2010	02GALION	345	VM drop to 355kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 355 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
11	12/1/2010	DORSEY 2	500	VM drop to 489kV	The innage of two DORSEY 2 500 kV buses was identified to be the cause for the voltage fluctuation at DORSEY 2 500 kV bus (both were initially at 500 kV; but after connecting one went up to 525.2 kV while the other went down to 489.4 kV). The Shunt Capacitor operation might also have a role in it. The flows in the lines appear to be genuine.

12	12/8/2010	HAZLTON	345	VM drop to 342kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 342 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
13	1/20/2011	FORBTAP	500	VM rise to 525kV	The outages of CHIS CO 34.5 and CHIS CO 345 kV buses were identified to be the cause for the voltage rise at FORBTAP 500 kV bus. The flows in the lines appear to be genuine except in the Before event case of CHIS CO 345 kV bus.
14	1/26/2011	HURON 3	345	VM rise to 368kV	The voltage fluctuations were due to: (a) Disconnection of HURON 345 kV bus from rest of the system, (b) Reconnection of HURON 345 kV bus with ANTELOP 345 kV bus, (c) Disconnection of HURON 345 kV bus from the rest of the system, (d) Reconnection of HURON 345 kV bus with the rest of the system. The flows in the lines appear to be genuine.
15	1/28/2011	FTTHOMP	345	VM drop below 350kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage fluctuation was believed to be due to change in loading of FTTHOMP 345 kV bus.
16	1/30/2011	08WHEATC	345	VM drop to 339kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 340 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
17	2/2/2011	FORBTAP	500	VM rise to 547kV	The outage and innage of FORBTAP-CHIS CO 500 kV line was identified to be the cause for the voltage fluctuation at FORBTAP 500 kV bus. The flows in the lines appear to be genuine but the mismatches were found to be high as well
18	2/4/2011	08NUCOR	345	VM drop to 332kV	The outage of 08NUCOR-08CAYUGA 345 kV line was identified to be the cause for the voltage fluctuation at 08NUCOR 345 kV bus. The flows in the lines appear to be genuine.
19	2/7/2011	PLAINS	345	VM drop to 343kV	The outage of PLAINS-MGN 345 kV line was identified to be the cause for the voltage fluctuation at PLAINS 345 kV bus. The flows in the lines appear to be genuine.
20	2/8/2011	PLAINS	345	VM drop to 343kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 343 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
21	2/10/2011	FORBTAP	500	VM rise to 522kV	The outages at CHIS CO 34.5 and CHIS CO 345 kV buses were identified to be the cause for the voltage rise at FORBTAP 500 kV bus. The flows in the lines appear to be genuine but the mismatches for the CHIS CO 345 kV bus were found to be high as well.
22	2/25/2011	FTTHOMP	345	VM drop below 350kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage fluctuation was believed to be due to change in loading of FTTHOMP 345 kV bus.
23	3/1/2011	JAMESTN3	345	VM drop to 328kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage fluctuation was believed to be due to change in loading of JAMESTN3 345 kV bus.
24	3/1/2011	FTTHOMP	345	VM drop below 350kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage fluctuation was believed to be due to change in loading of FTTHOMP 345 kV bus.

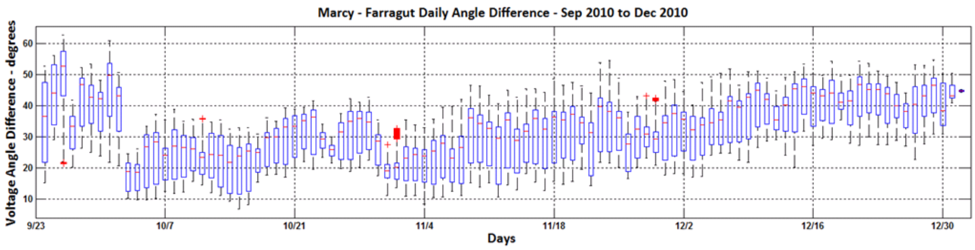
25	3/6/2011	REDWILO3	345	VM rise to 371kV	The innage of the REDWILO 1 kV-REDWILO7 115 kV line was identified to be the cause for the voltage rise at REDWILO 345 kV bus. The flows in the lines appear to be genuine.
26	3/8/2011	DICKNSN3	345	VM rise to 362kV	The change in loadings of COALCR4 230 kV bus and DICKNSN3 345 kV buses were identified to be the cause for the voltage fluctuation at DICKNSN3 345 kV bus. The high mismatch values also indicate that the flows may not be genuine.
27	3/16/2011	EAUCL3	345	VM drop below 340kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 340 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
28	3/17/2011	EAUCL3	345	VM drop below 321.8kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage fluctuation was believed to be due to change in loading of EAUCL3 345 kV bus.
29	3/21/2011	BONDRNT3	345	VM rise to 367kV	The voltage fluctuations were due to: (a) Disconnection of BONDRNT3 345 kV bus from rest of the system, (b) Connection of BONDRNT3 345 kV bus with MNTZUMA3 345 kV bus, (c) Reconnection of BONDRNT3 345 kV bus with GDMEC 345 kV bus. The flows in the lines appear to be genuine but the mismatches were found to be high as well.
30	3/22/2011	05REYNOL	345	VM drop to 336kV	The outages at 17GODLND 138 kV bus was identified to be the cause for the voltage fluctuation at 05REYNOL 345 kV bus. The flows in the lines appear to be genuine except in the Event case of 17GODLND 138 kV bus.
31	3/24/2011	GR_ISLD	345	VM rise to 373kV	The voltage fluctuations were due to: (a) Connection of GR_ISLD 345 kV bus with rest of the system, (b) Disconnection of one GR_ISLD 345 kV bus from the other GR_ISLD 345 kV bus as well as from FTTHOMP3 345 kV bus, (c) Reconnection of both GR_ISLD 345 kV buses with rest of the system. The flows in the lines appear to be genuine.
32	3/27/2011	08NUCOR	345	VM rise to 358kV	The outage of 08NUCOR-08WHITST 345 kV line was identified to be the cause for the voltage fluctuation at 08NUCOR 345 kV bus. The flows in the lines appear to be genuine.
33	3/31/2011	ROSEAUN2	500	VM drop to 513kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 513 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
34	4/1/2011	ROSEAUN2	500	VM drop to 512kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine but the mismatches were found to be high as well. The voltage fluctuation was believed to be due to change in loading of ROSEAUN2 500 kV bus.
35	4/4/2011	DICKNSN3	345	VM drop to 340kV	The change in loadings of DICKNSN3 230 kV bus and DICKNSN3 345 kV buses were identified to be the cause for the voltage fluctuation at DICKNSN3 345 kV bus. The flows in the lines appear to be genuine.
36	4/4/2011	17LESBRG	345	VM drop to 342kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 342 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
37	4/12/2011	ROSEAUN2	500	VM drop to 512kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine but the mismatches were found to be high as well. The voltage fluctuation was believed to be due to change in loading of ROSEAUN2 500 kV bus.

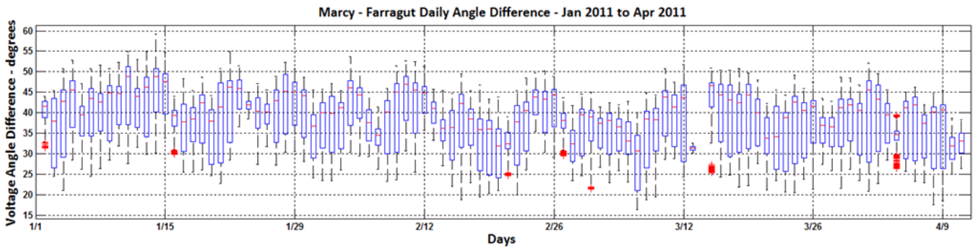
38	4/16/2011	02SHNAGO	345	VM rise to 356kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 356 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
39	4/18/2011	HAZLTON	345	VM drop to 342kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 344 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified. Also for this case, the outlier was supposed to be due to the voltage dropping to 342 kV but the lowest voltage was found to be 344 kV.
40	4/19/2011	08FRNCSC	345	VM rise to 380kV	The outage of 08FRNCSC-08GIBSON 345 kV line was identified to be the cause for the voltage fluctuation at 08FRNCSC 345 kV bus. The flows in the lines appear to be genuine but the mismatches were found to be high as well.
41	4/20/2011	08FRNCSC	345	VM rise to 376kV	The innage of 08FRNCSC-08GIBSON 345 kV line was identified to be the cause for the voltage fluctuation at 08FRNCSC 345 kV bus. The flows in the lines appear to be genuine but the mismatches were found to be high as well.
42	4/21/2011	FTTHOMP	345	VM rise to 370kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 370 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.
43	4/24/2011	02GALION	345	VM rise to 355kV	No significant changes in flow or system conditions were identified. The flows in the lines appear to be genuine. The voltage hovered around 355 kV for more than one state estimator case. But since there were no sharp transitions in the voltage profile, neither an event case nor a potential cause could be identified.

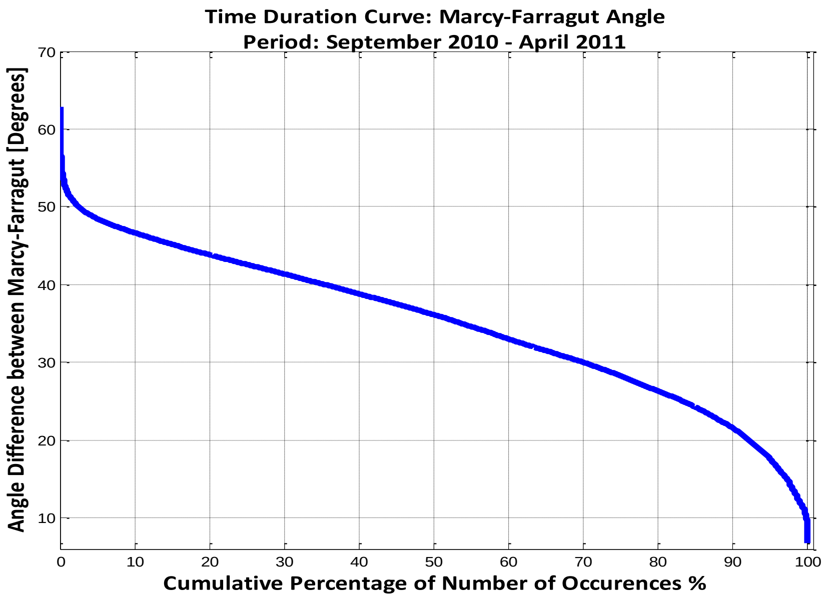
A.5 NYISO Selected Angle Pairs Box Whisker Plots and Time Duration Plots

DISTRIBUTION PLOTS

1. MARCY- FARRAGUT Angle:







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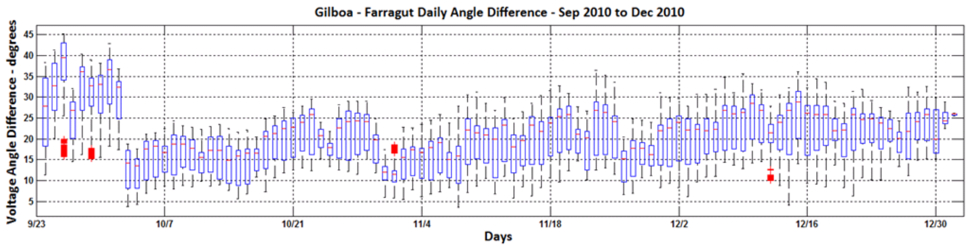
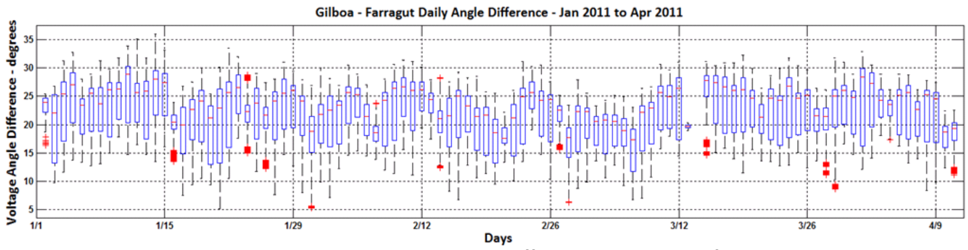
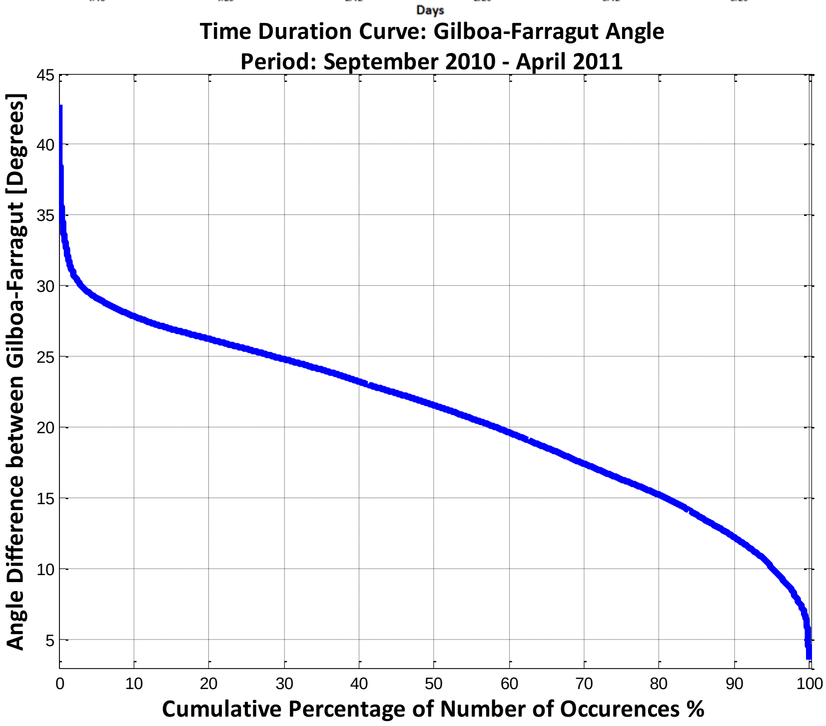
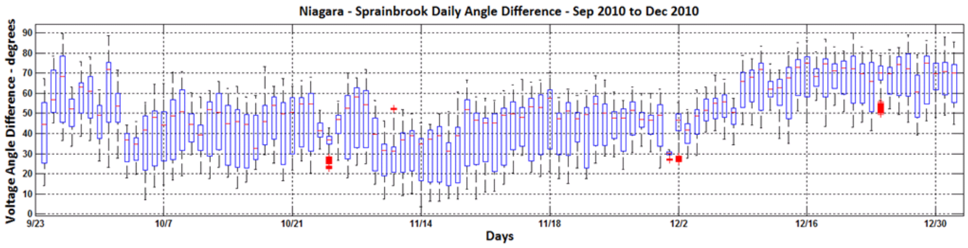
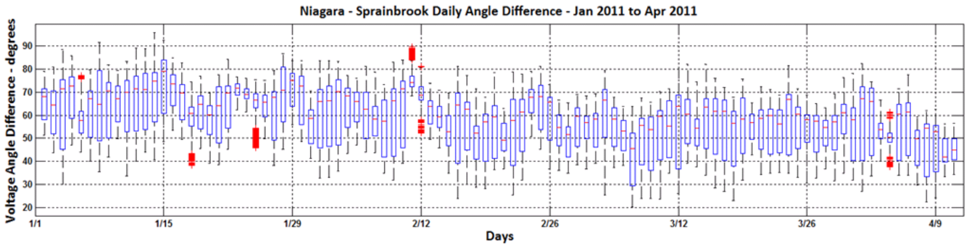


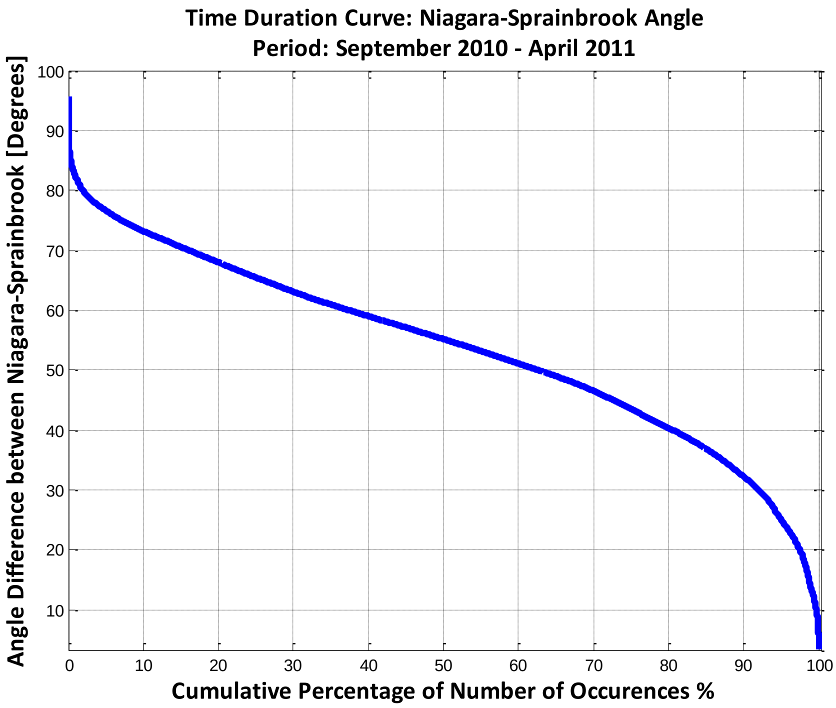




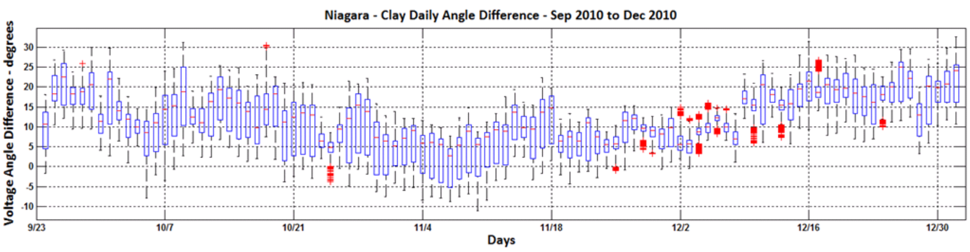
3. NIAGARA – SPRAINBROOK Angle:

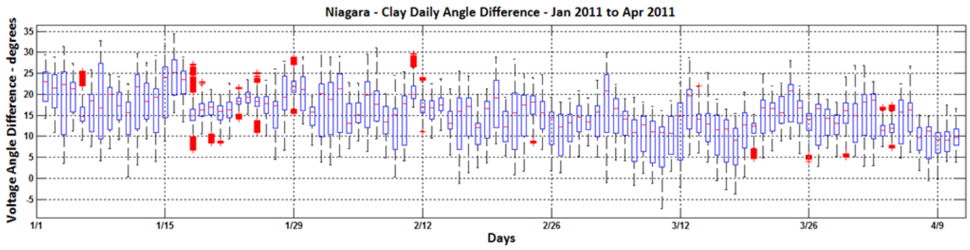


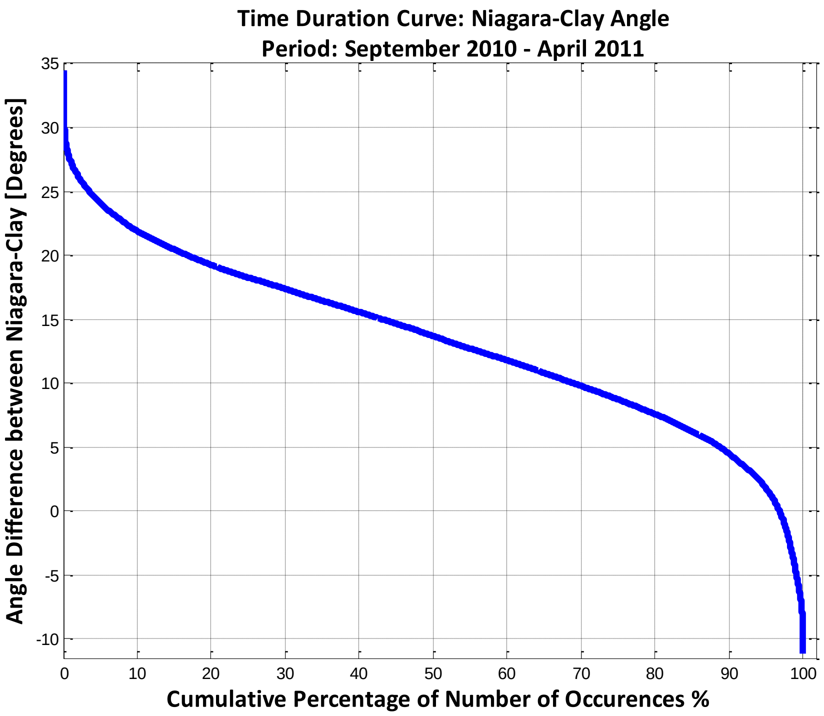




4. NIAGARA – CLAY Angle:







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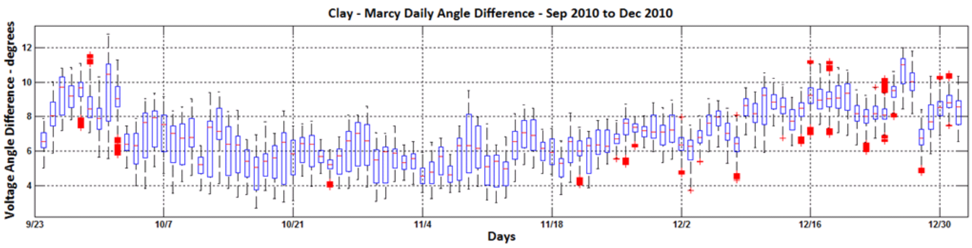
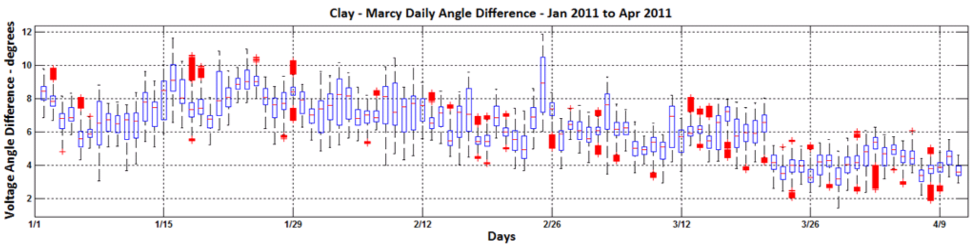
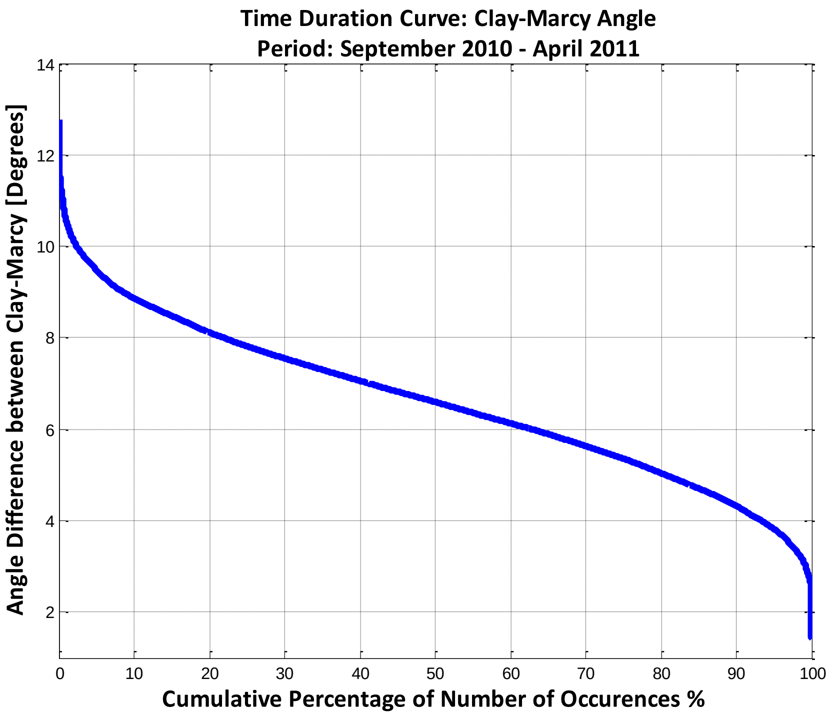
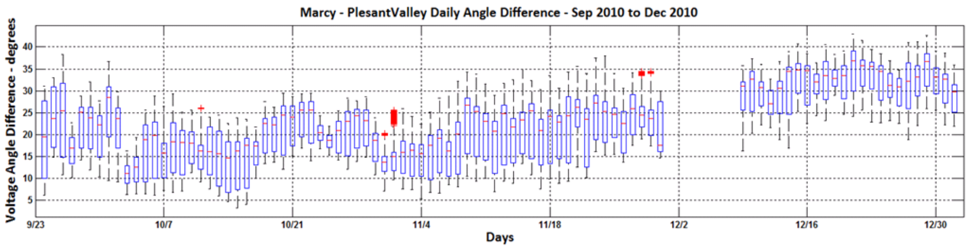
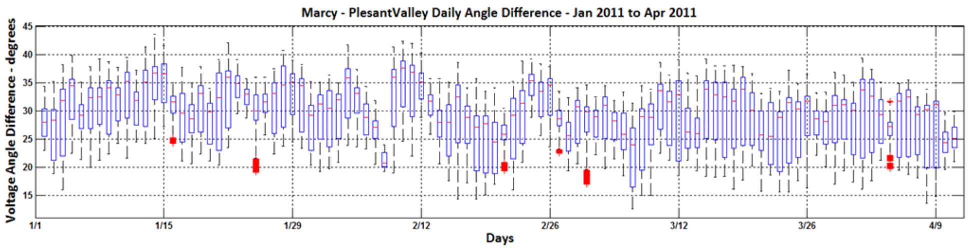


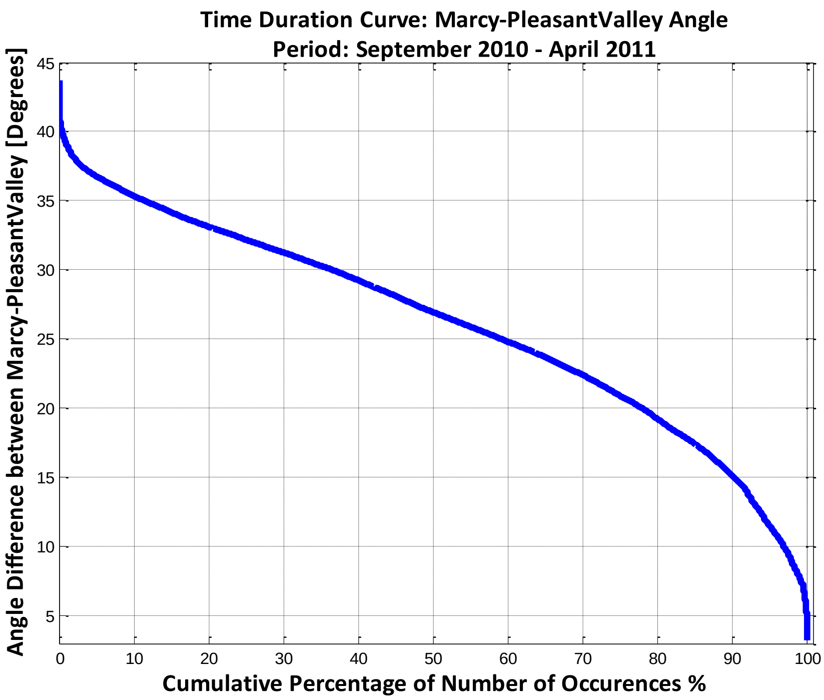




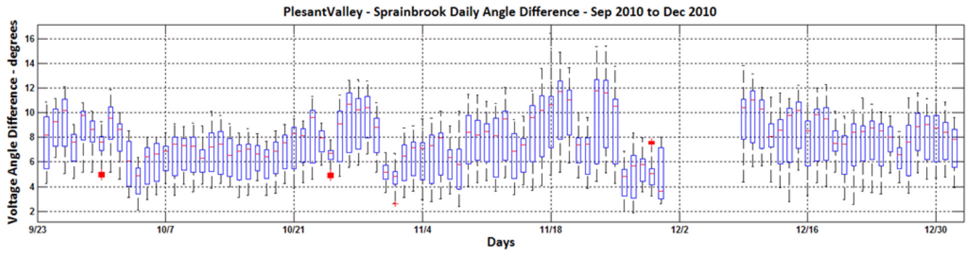
6. MARCY – PLESANT VALLEY Angle:

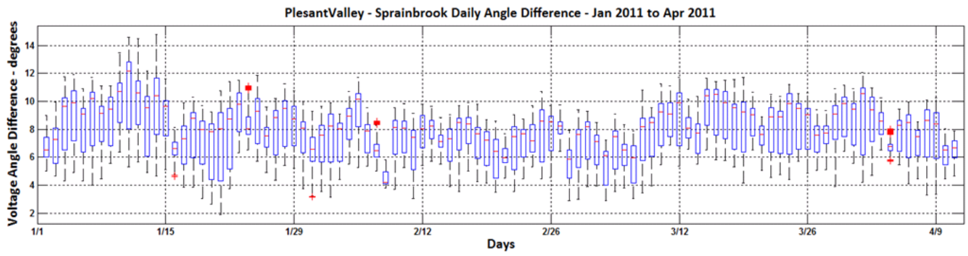


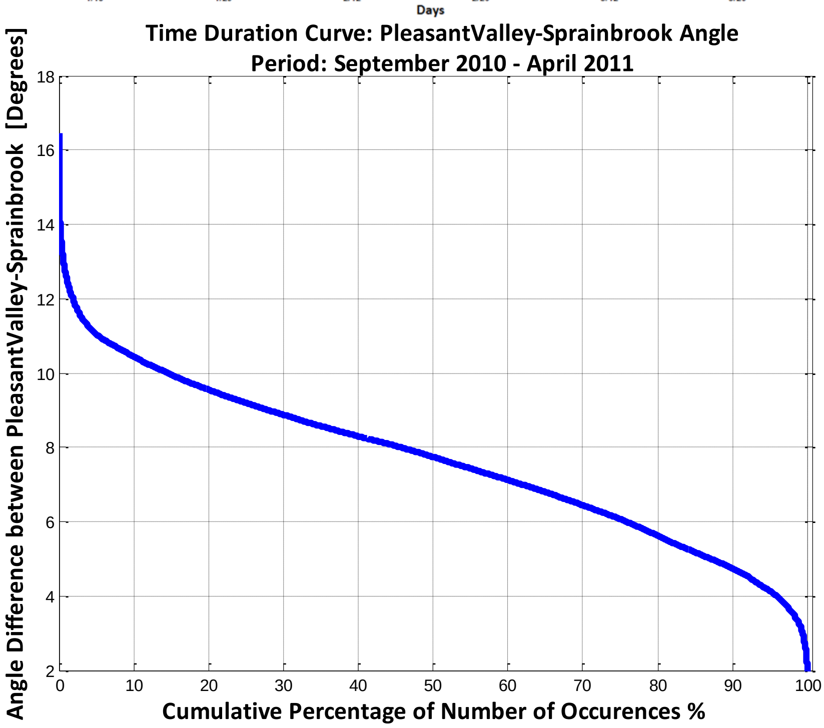




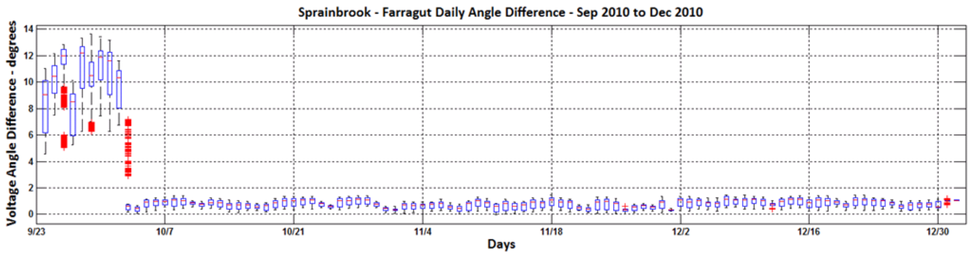
7. PLESANTVALLEY – SPRAINBROOK Angle:

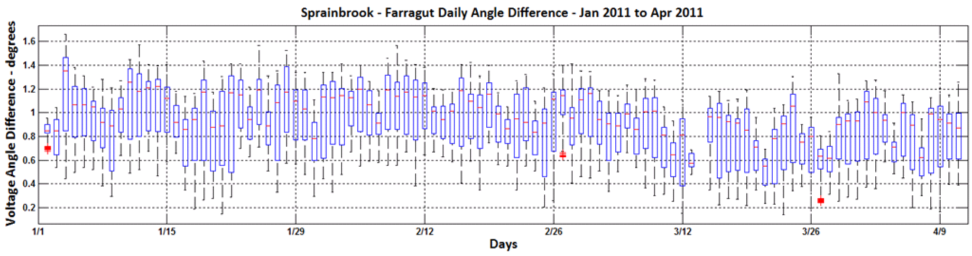


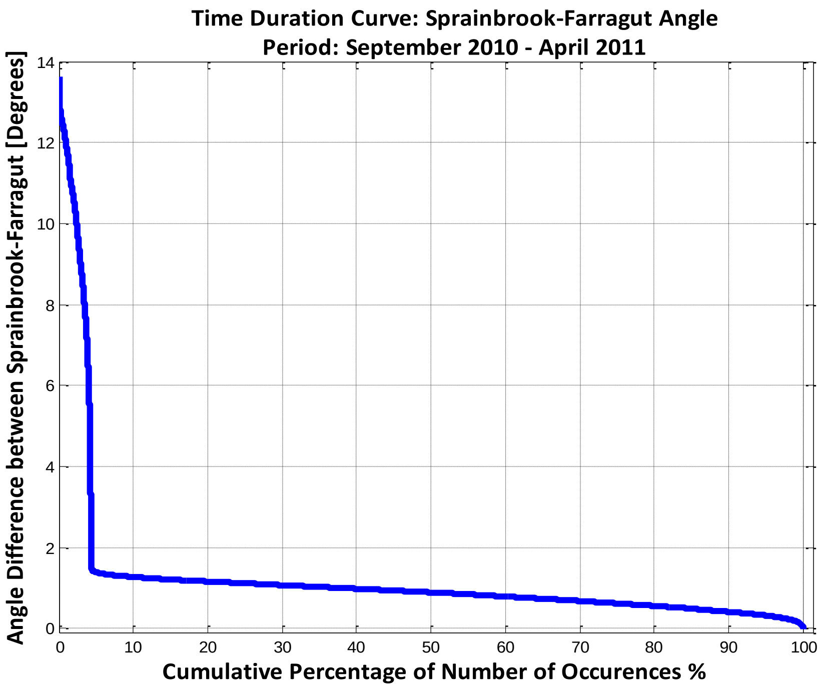




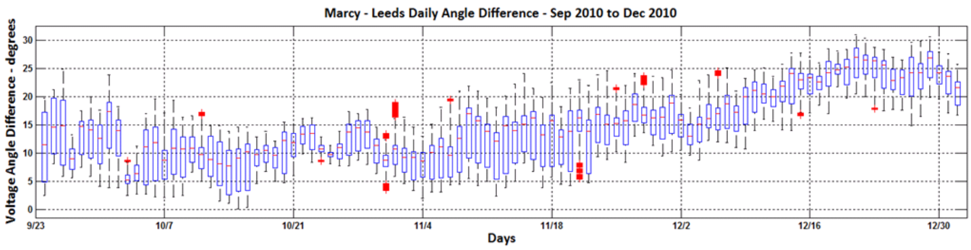
8. SPRAINBROOK – FARRAGUT Angle:

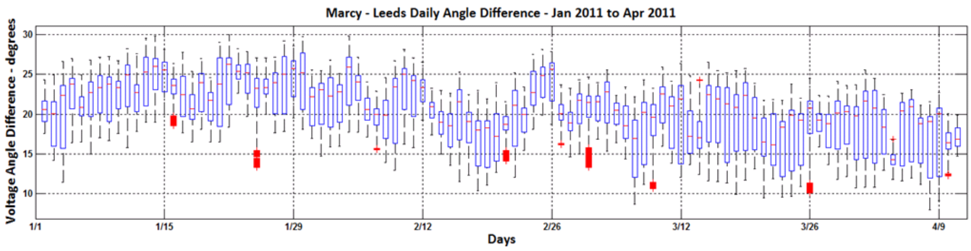


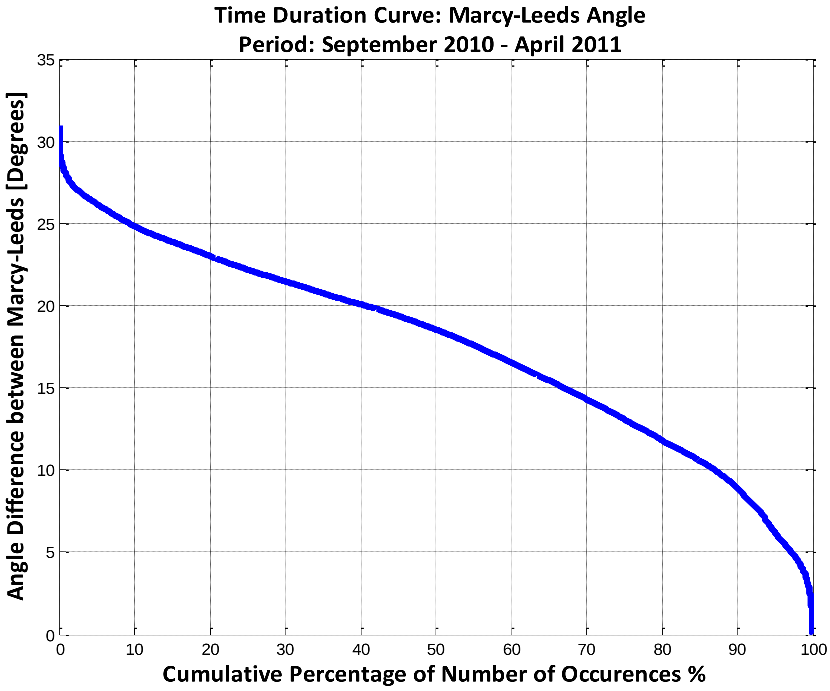




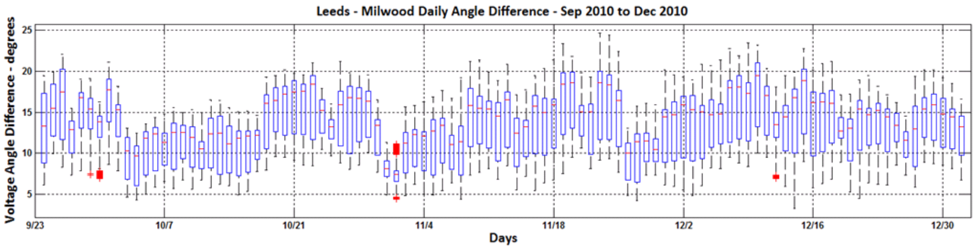
9. MARCY – LEEDS Angle:

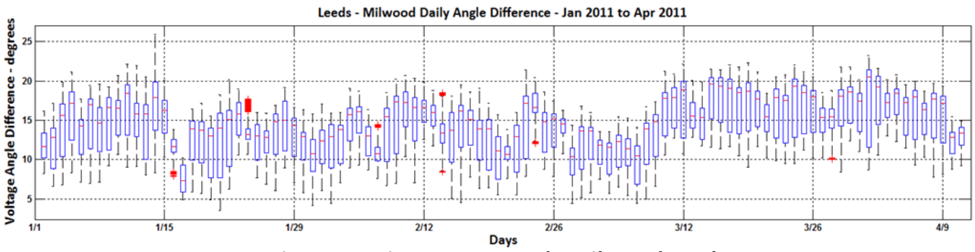


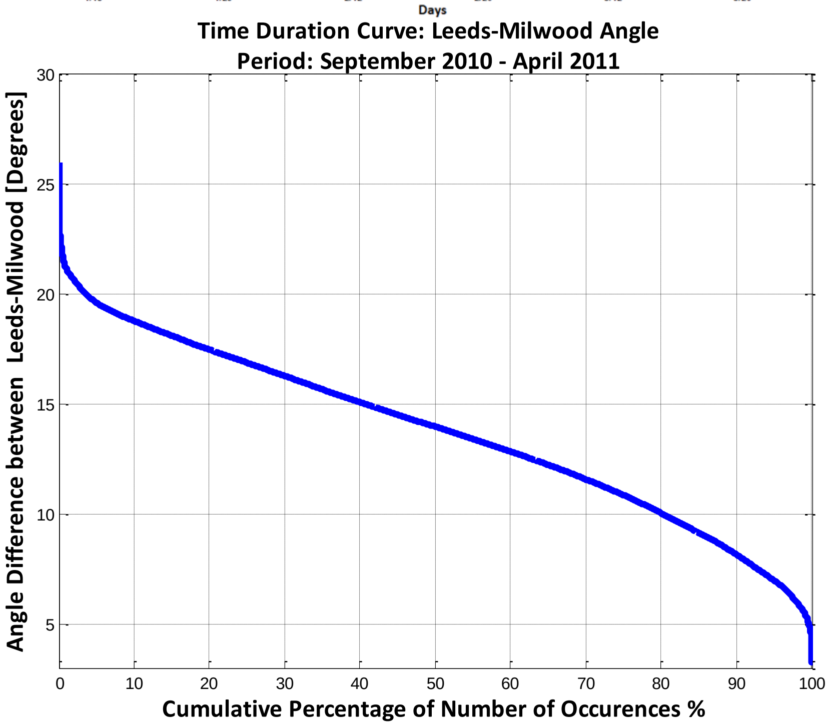




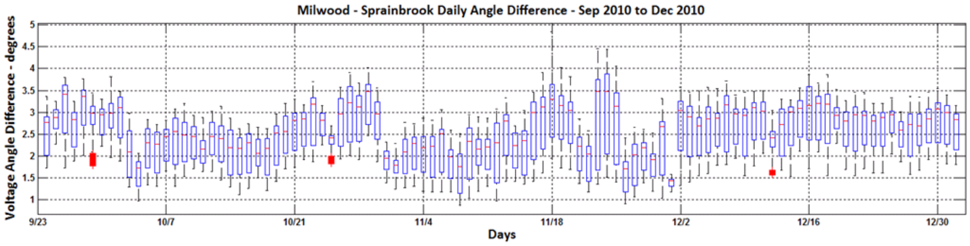
10. LEEDS – MILWOOD Angle:

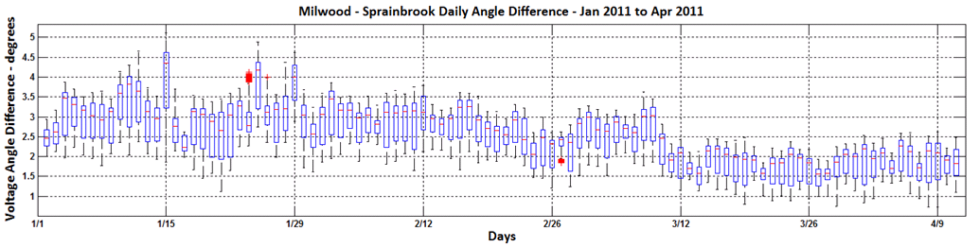


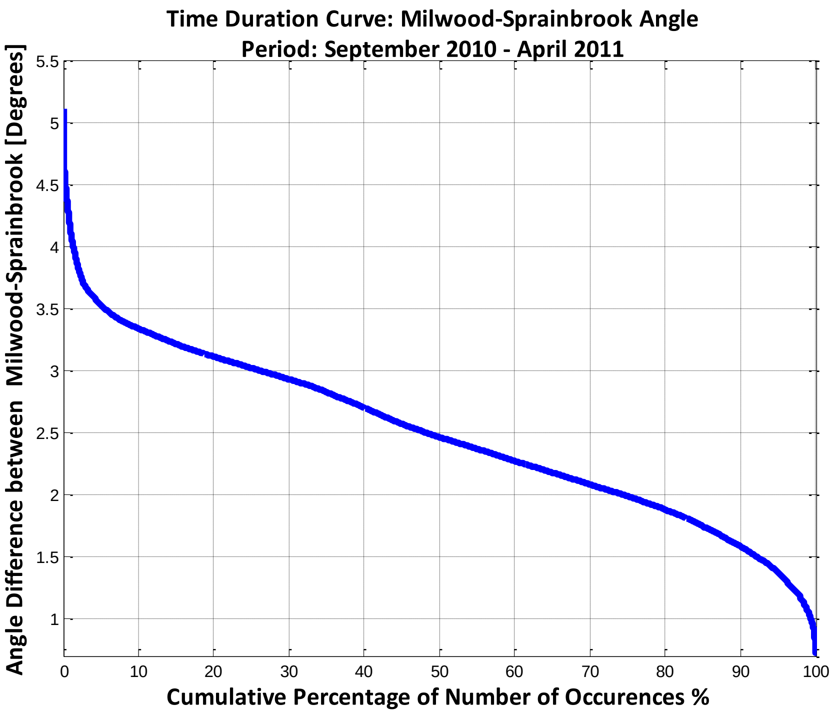




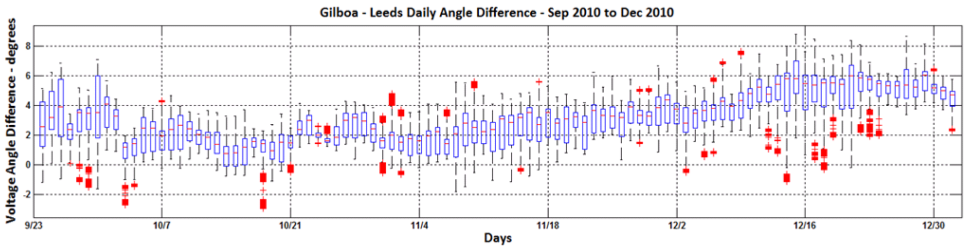
11. MILWOOD – SPRAINBROOK Angle:

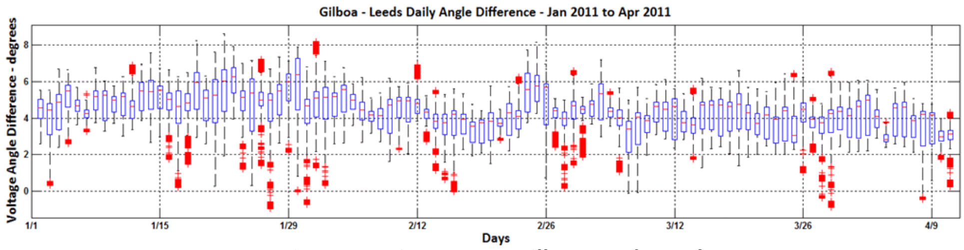


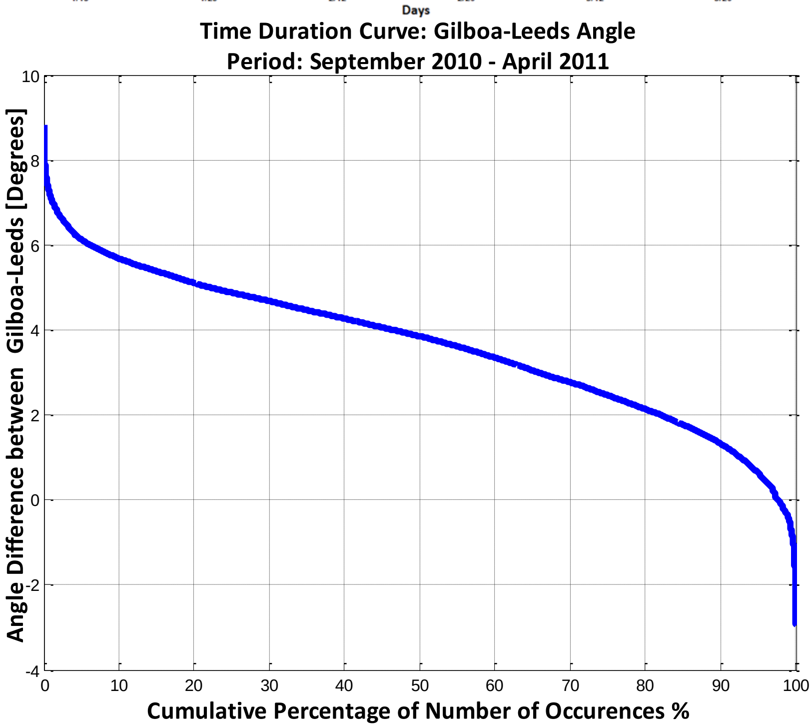




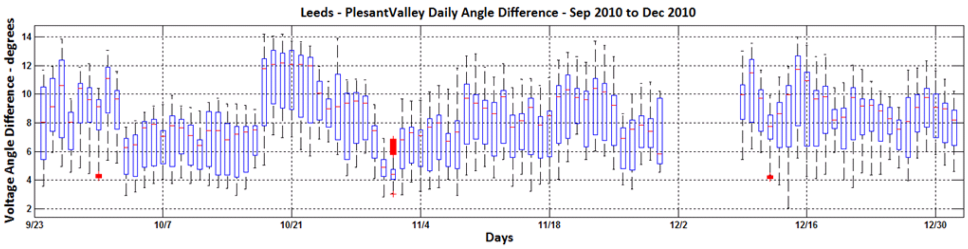
12. GILBOA – LEEDS Angle:

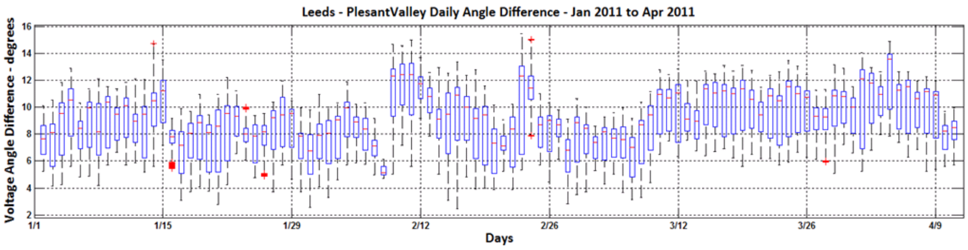


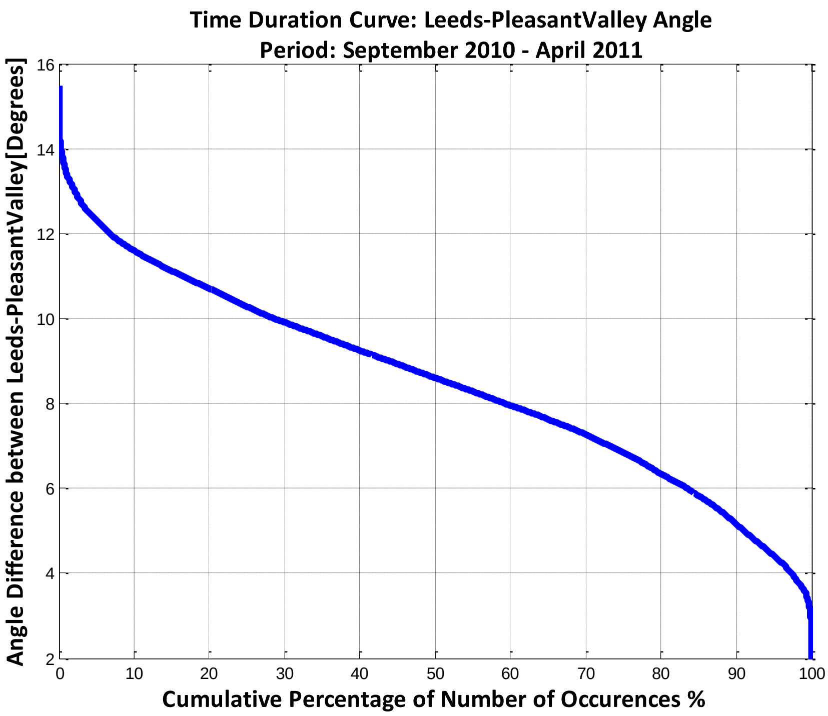




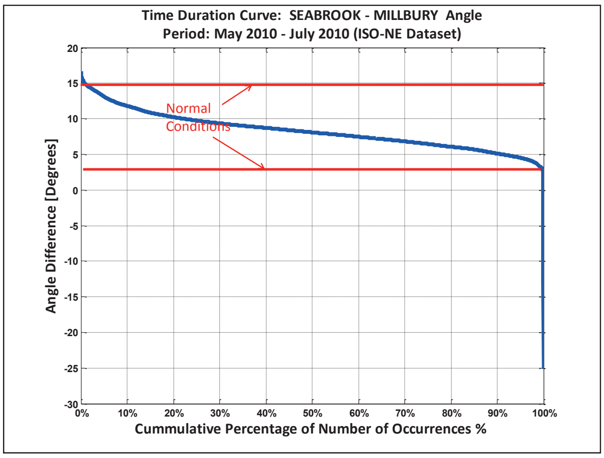
13. LEEDS – PLESANTVALLEY Angle:

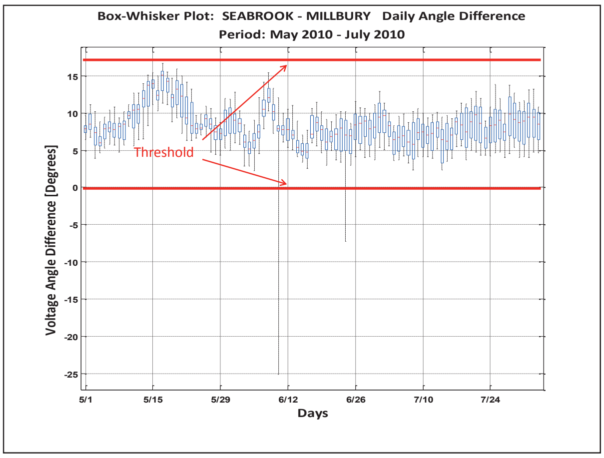

Leeds - PlesantValley Daily Angle Difference - Sep 2010 to Dec 2010
Voltage Angle Difference - degrees
Days
9/23
10/7
10/21
11/4
11/18
12/2
12/16
12/30

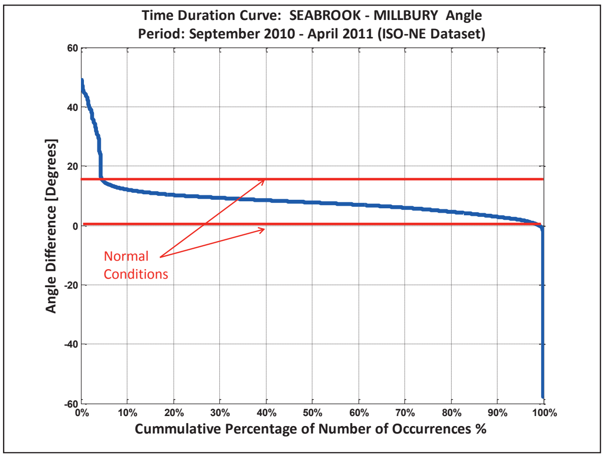

Leeds - PlesantValley Daily Angle Difference - Jan 2011 to Apr 2011
Voltage Angle Difference - degrees
Days
1/1
1/15
1/29
2/12
2/26
3/12
3/26
4/9

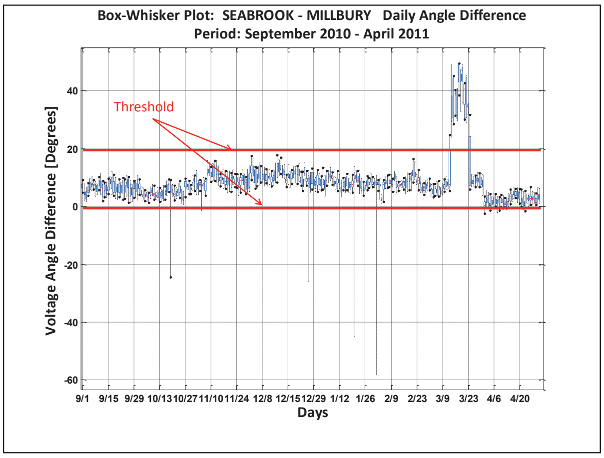

Time Duration Curve: Leeds-PleasantValley Angle
Period: September 2010 - April 2011
Angle Difference between Leeds-PleasantValley[Degrees]
Cumulative Percentage of Number of Occurences %

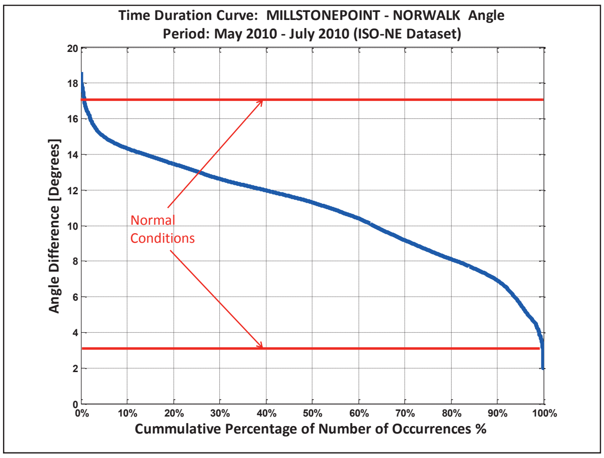
A.6 ISONE Selected Angle Pairs Box Whisker Plots and Time Duration Plots

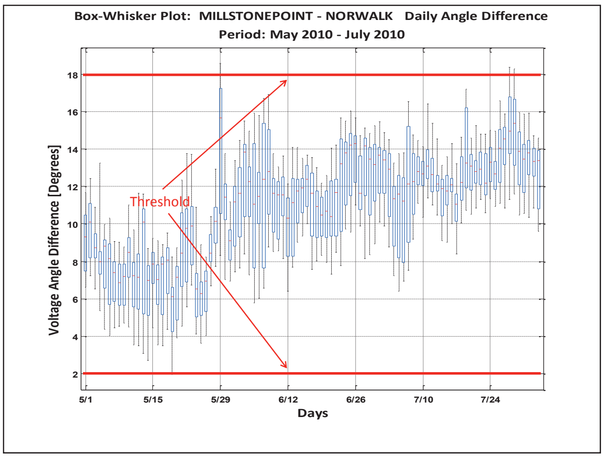


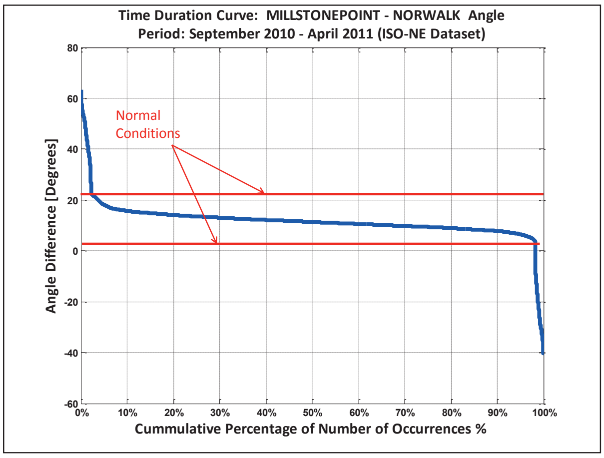


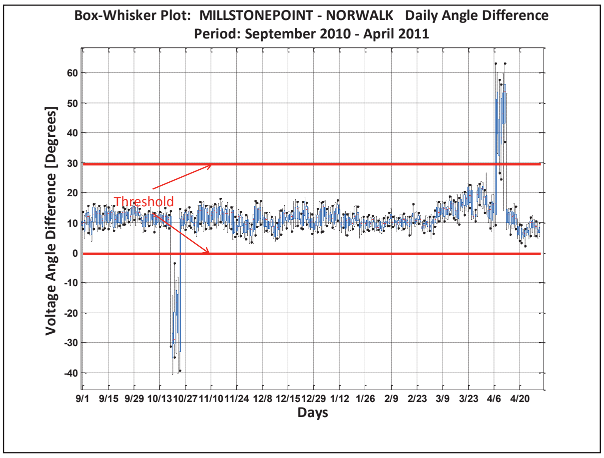


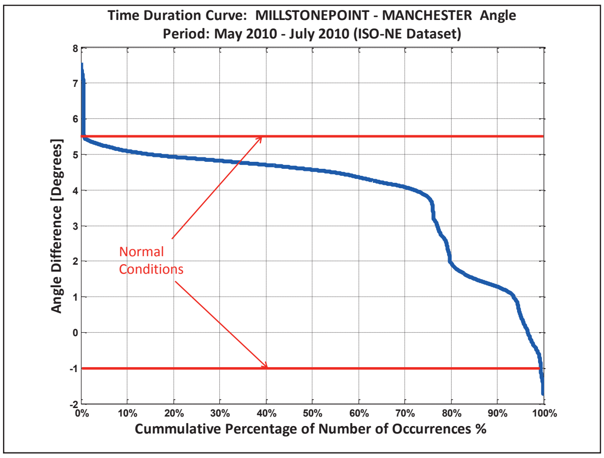



Time Duration Curve: MILLSTONEPOINT - NORWALK Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal
Conditions
Cummulative Percentage of Number of Occurrences %

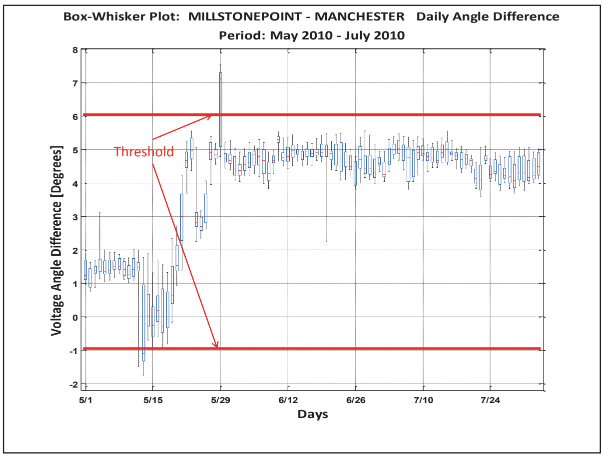

Box-Whisker Plot: MILLSTONEPOINT - NORWALK Daily Angle Difference
Period: May 2010 - July 2010
Voltage Angle Difference [Degrees]
Threshold
Days


Time Duration Curve: MILLSTONEPOINT - NORWALK Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal
Conditions
Cummulative Percentage of Number of Occurrences %

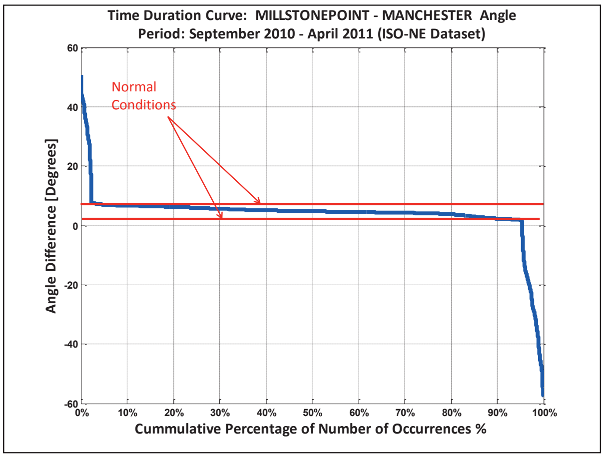

Box-Whisker Plot: MILLSTONEPOINT - NORWALK Daily Angle Difference
Period: September 2010 - April 2011
Voltage Angle Difference [Degrees]
Threshold
Days



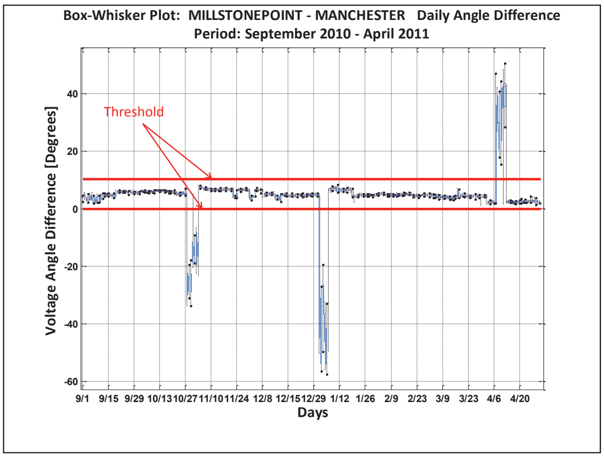
Time Duration Curve: MILLSTONEPOINT - MANCHESTER Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal Conditions
Cummulative Percentage of Number of Occurrences %



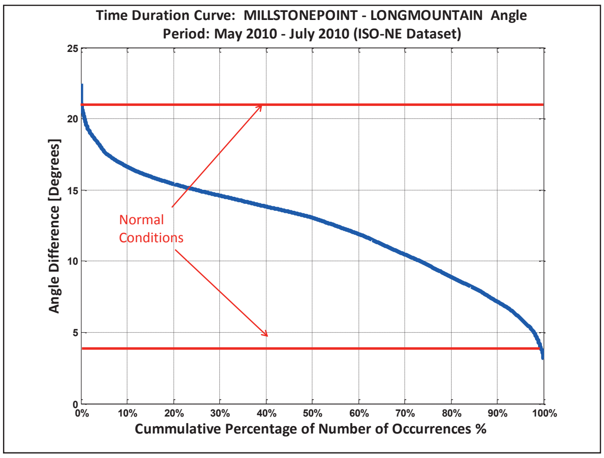
Box-Whisker Plot: MILLSTONEPOINT - MANCHESTER Daily Angle Difference
Period: May 2010 - July 2010
Voltage Angle Difference [Degrees]
Threshold
Days

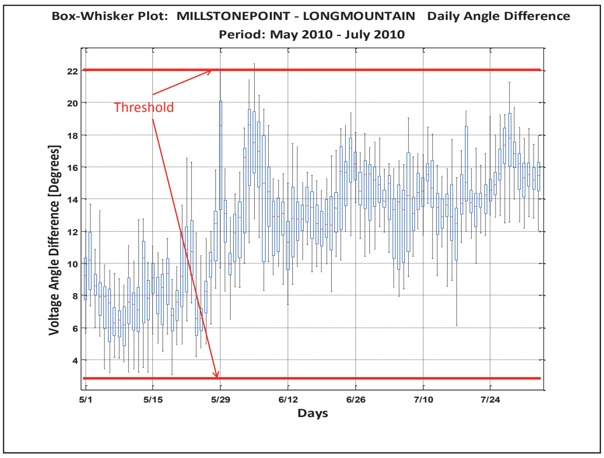


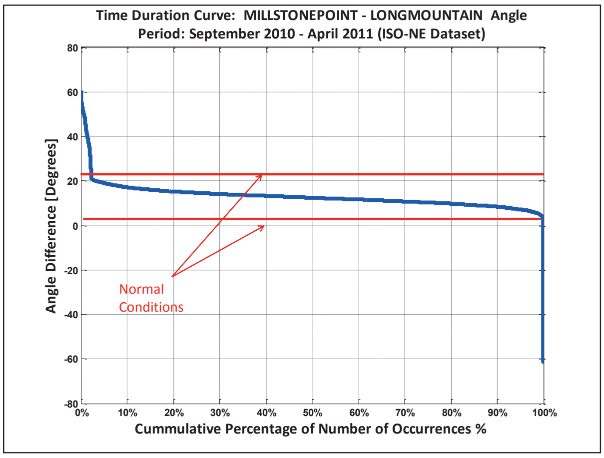
Time Duration Curve: MILLSTONEPOINT - MANCHESTER Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal Conditions
Cummulative Percentage of Number of Occurrences %

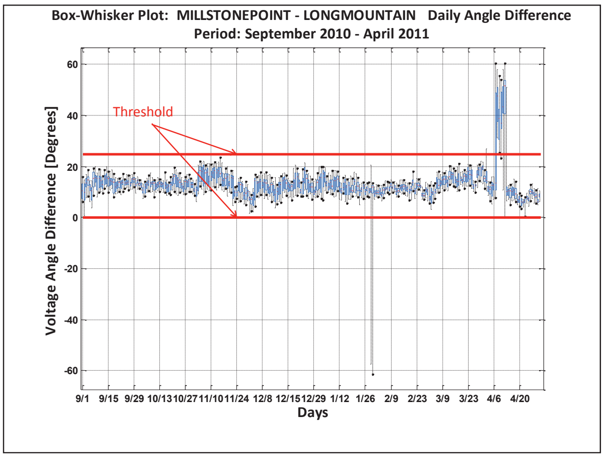


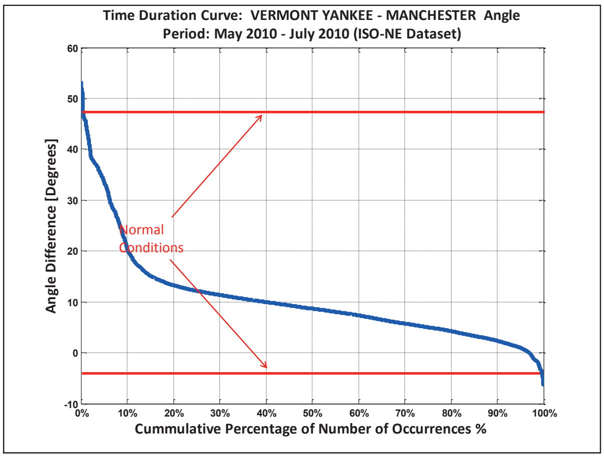
Box-Whisker Plot: MILLSTONEPOINT - MANCHESTER Daily Angle Difference
Period: September 2010 - April 2011
Voltage Angle Difference [Degrees]
Threshold
Days


Time Duration Curve: MILLSTONEPOINT - LONGMOUNTAIN Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal
Conditions
Cummulative Percentage of Number of Occurrences %

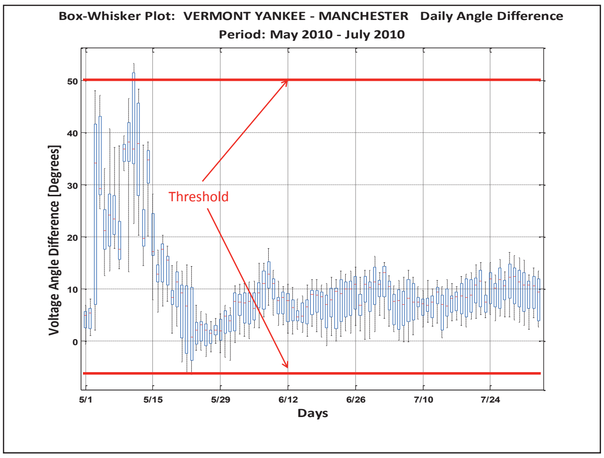

Box-Whisker Plot: MILLSTONEPOINT - LONGMOUNTAIN Daily Angle Difference
Period: May 2010 - July 2010
Threshold
Voltage Angle Difference [Degrees]
Days


Time Duration Curve: MILLSTONEPOINT - LONGMOUNTAIN Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal
Conditions
Cummulative Percentage of Number of Occurrences %

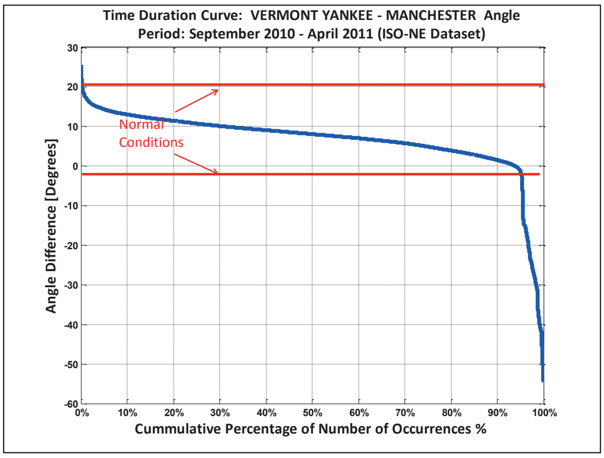

Box-Whisker Plot: MILLSTONEPOINT - LONGMOUNTAIN Daily Angle Difference
Period: September 2010 - April 2011
Threshold
Voltage Angle Difference [Degrees]
Days



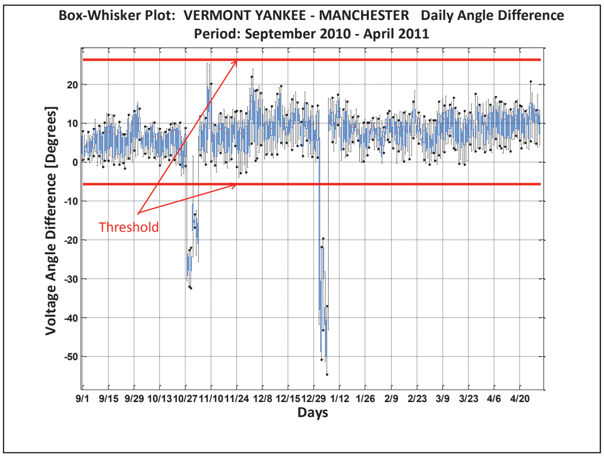
Time Duration Curve: VERMONT YANKEE - MANCHESTER Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal Conditions
Cummulative Percentage of Number of Occurrences %



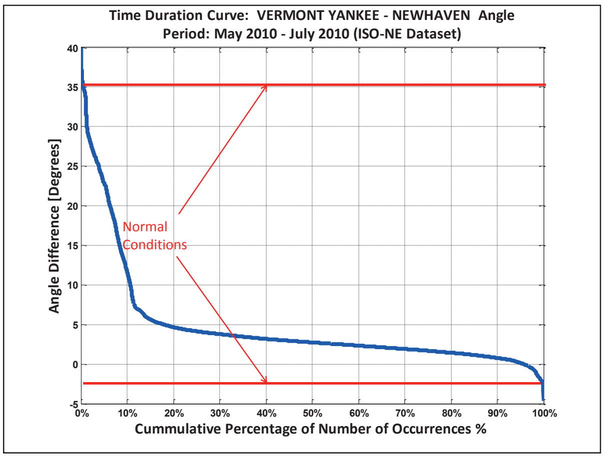
Box-Whisker Plot: VERMONT YANKEE - MANCHESTER Daily Angle Difference
Period: May 2010 - July 2010
Voltage Angle Difference [Degrees]
Threshold
Days

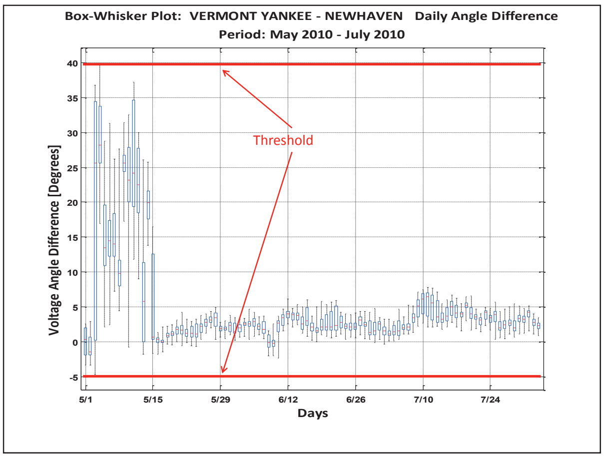


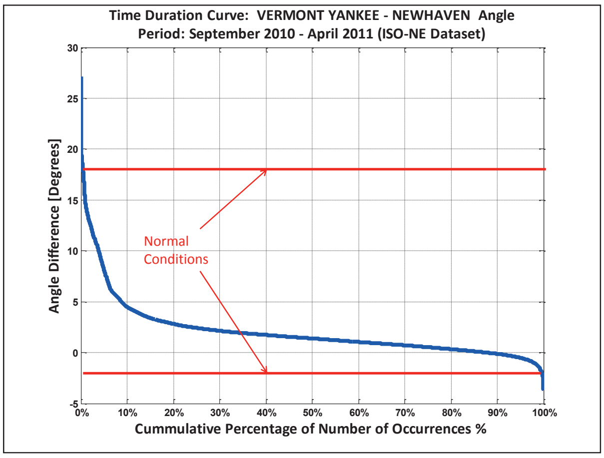
Time Duration Curve: VERMONT YANKEE - MANCHESTER Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal Conditions
Cummulative Percentage of Number of Occurrences %

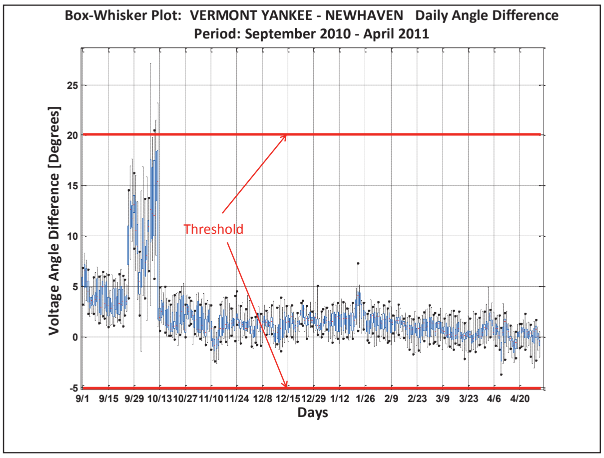


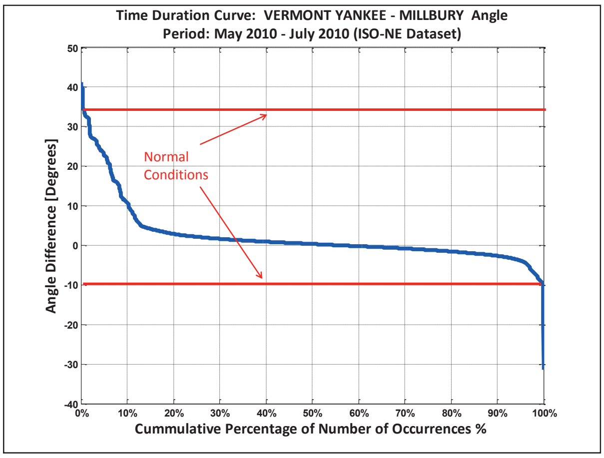
Box-Whisker Plot: VERMONT YANKEE - MANCHESTER Daily Angle Difference
Period: September 2010 - April 2011
Voltage Angle Difference [Degrees]
Threshold
Days

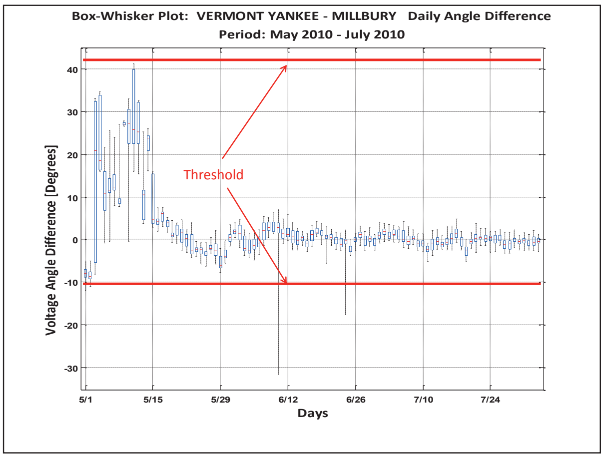

Time Duration Curve: VERMONT YANKEE - NEWHAVEN Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal
Conditions
Cummulative Percentage of Number of Occurrences %

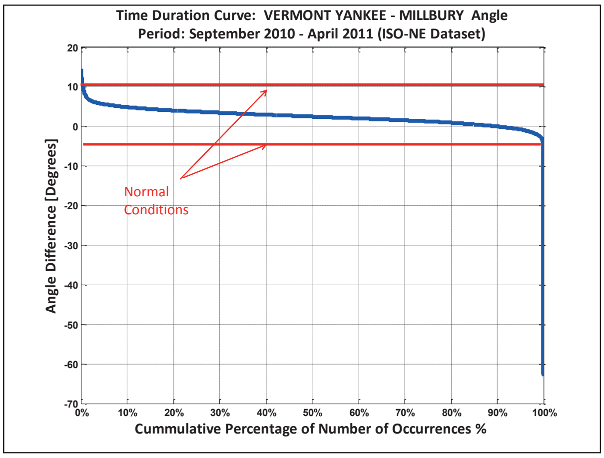

Box-Whisker Plot: VERMONT YANKEE - NEWHAVEN Daily Angle Difference
Period: May 2010 - July 2010
Voltage Angle Difference [Degrees]
Threshold
Days

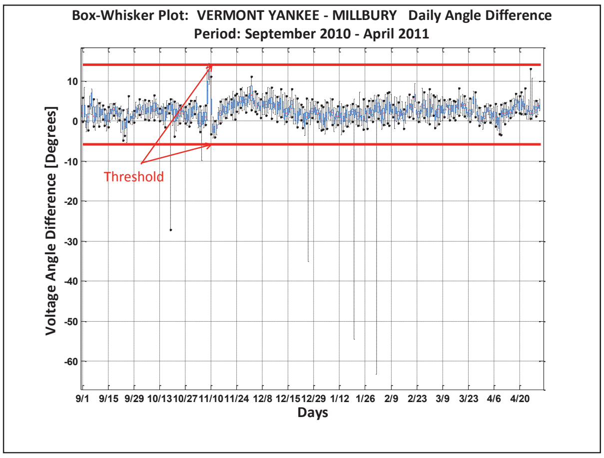

Time Duration Curve: VERMONT YANKEE - NEWHAVEN Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal
Conditions
Cummulative Percentage of Number of Occurrences %

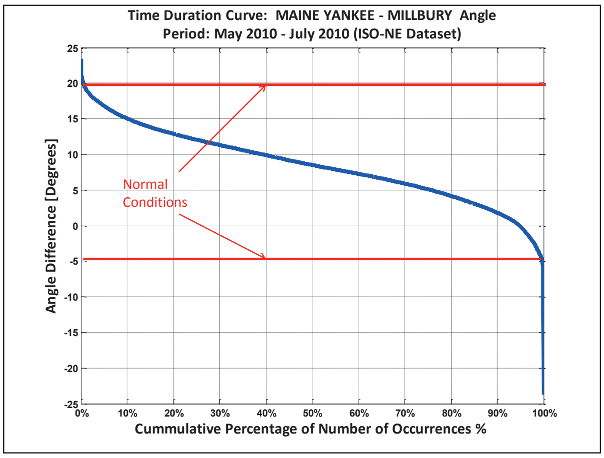

Box-Whisker Plot: VERMONT YANKEE - NEWHAVEN Daily Angle Difference
Period: September 2010 - April 2011
Voltage Angle Difference [Degrees]
Threshold
Days

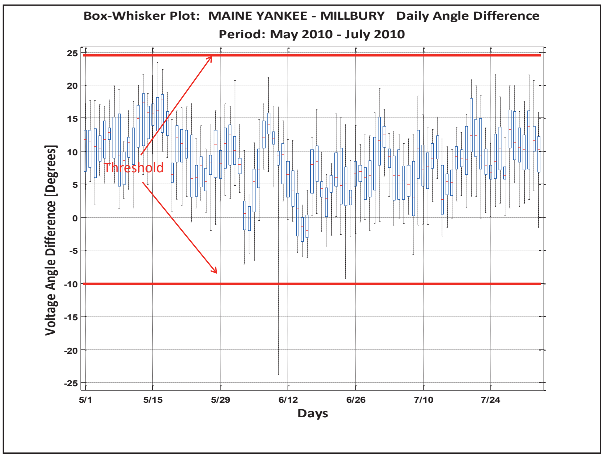

Time Duration Curve: VERMONT YANKEE - MILLBURY Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal
Conditions
Cummulative Percentage of Number of Occurrences %

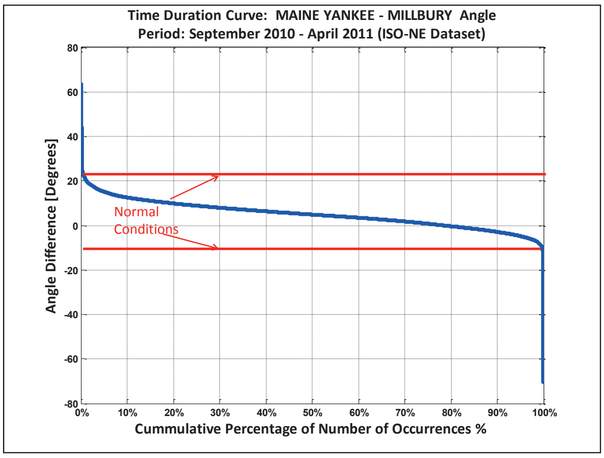

Box-Whisker Plot: VERMONT YANKEE - MILLBURY Daily Angle Difference
Period: May 2010 - July 2010
Voltage Angle Difference [Degrees]
Threshold
Days

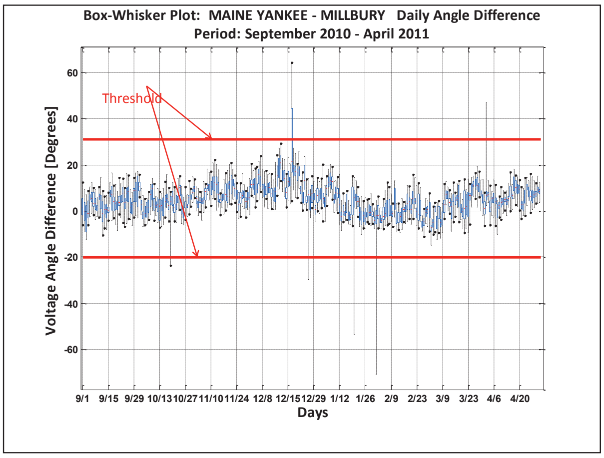

Time Duration Curve: VERMONT YANKEE - MILLBURY Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal
Conditions
Cummulative Percentage of Number of Occurrences %

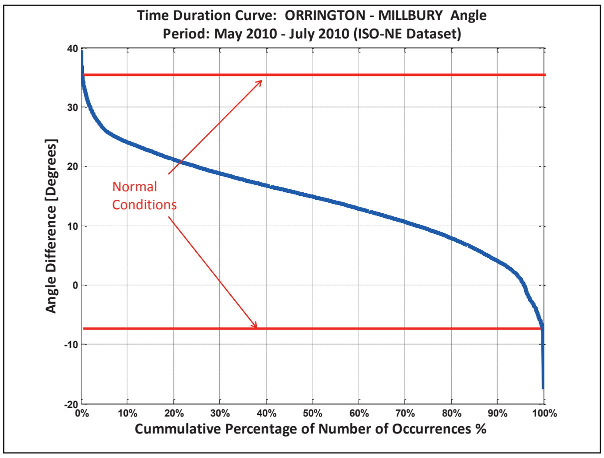

Box-Whisker Plot: VERMONT YANKEE - MILLBURY Daily Angle Difference
Period: September 2010 - April 2011
Voltage Angle Difference [Degrees]
Threshold
Days

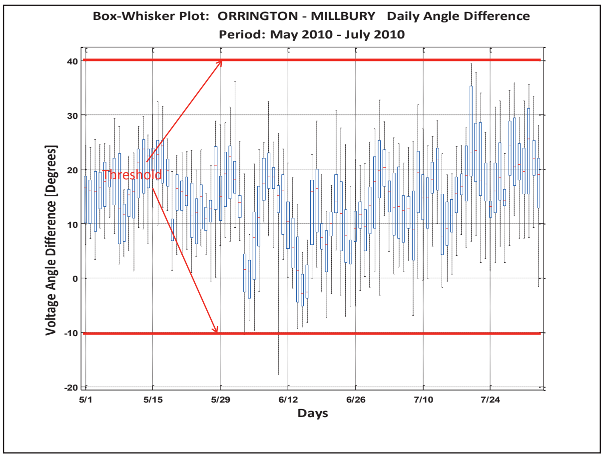

Time Duration Curve: MAINE YANKEE - MILLBURY Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Normal Conditions
Angle Difference [Degrees]
Cummulative Percentage of Number of Occurrences %

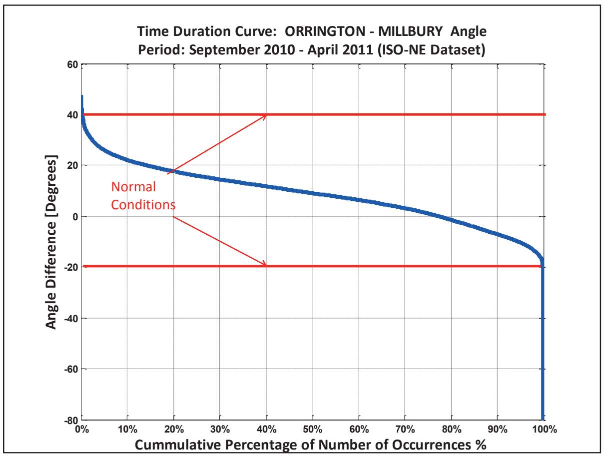

Box-Whisker Plot: MAINE YANKEE - MILLBURY Daily Angle Difference
Period: May 2010 - July 2010
Threshold
Voltage Angle Difference [Degrees]
Days

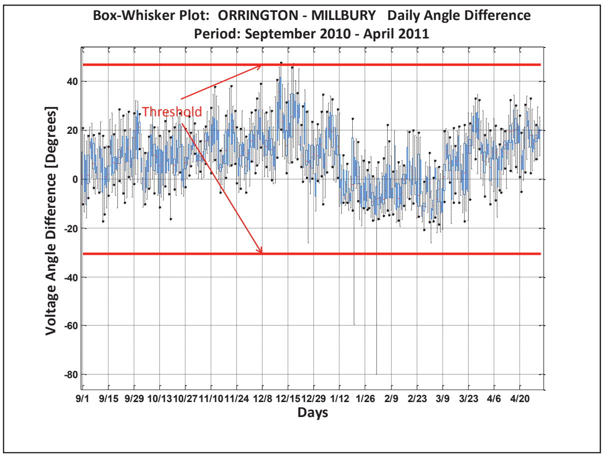

Time Duration Curve: MAINE YANKEE - MILLBURY Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Normal Conditions
Angle Difference [Degrees]
Cummulative Percentage of Number of Occurrences %

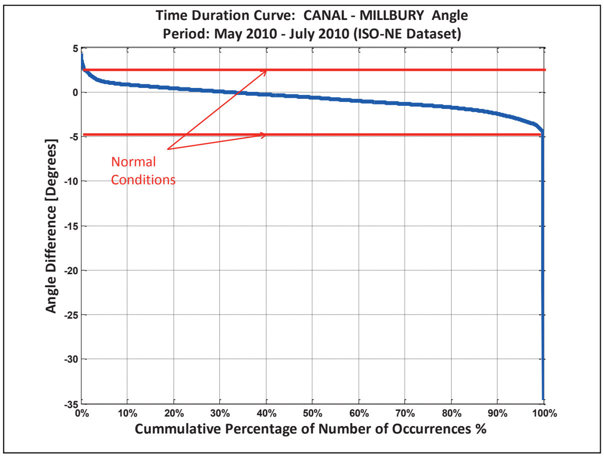

Box-Whisker Plot: MAINE YANKEE - MILLBURY Daily Angle Difference
Period: September 2010 - April 2011
Threshold
Voltage Angle Difference [Degrees]
Days

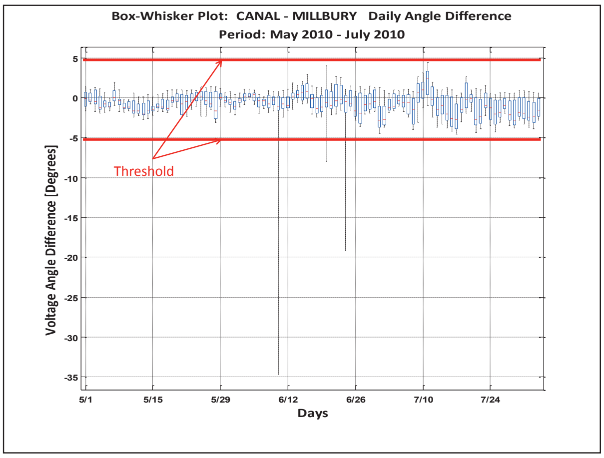

Time Duration Curve: ORRINGTON - MILLBURY Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal
Conditions
Cummulative Percentage of Number of Occurrences %

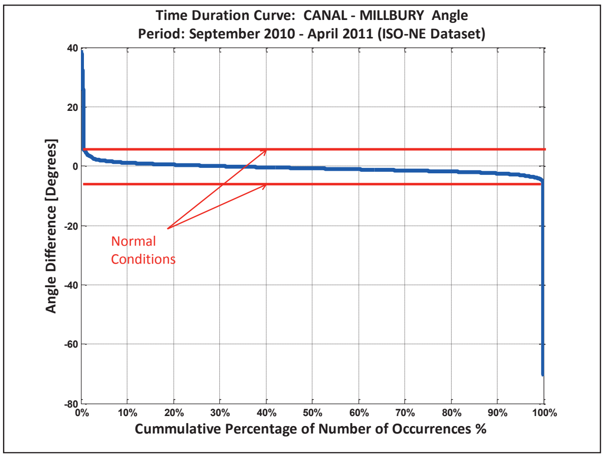

Box-Whisker Plot: ORRINGTON - MILLBURY Daily Angle Difference
Period: May 2010 - July 2010
Voltage Angle Difference [Degrees]
Threshold
Days

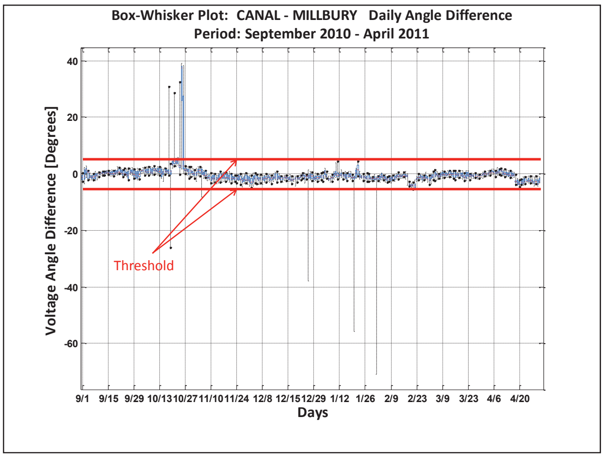

Time Duration Curve: ORRINGTON - MILLBURY Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal
Conditions
Cummulative Percentage of Number of Occurrences %

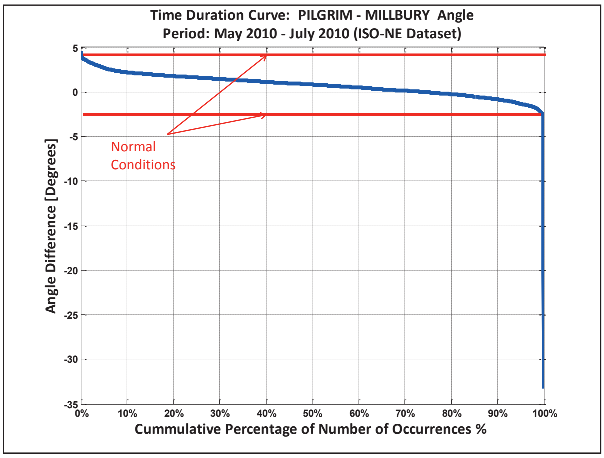

Box-Whisker Plot: ORRINGTON - MILLBURY Daily Angle Difference
Period: September 2010 - April 2011
Voltage Angle Difference [Degrees]
Threshold
Days

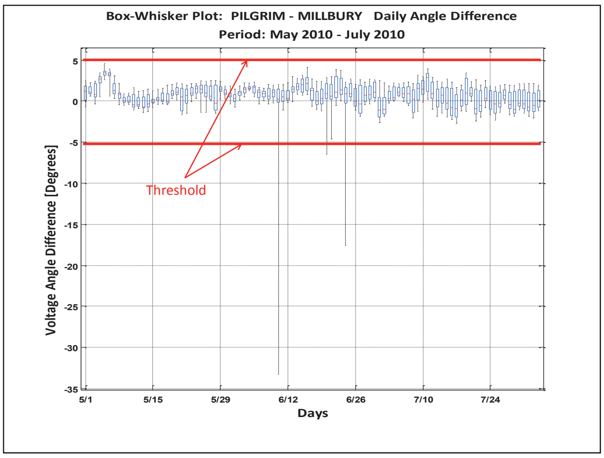

Time Duration Curve: CANAL - MILLBURY Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Angle Difference [Degrees]
Cummulative Percentage of Number of Occurrences %
Normal
Conditions

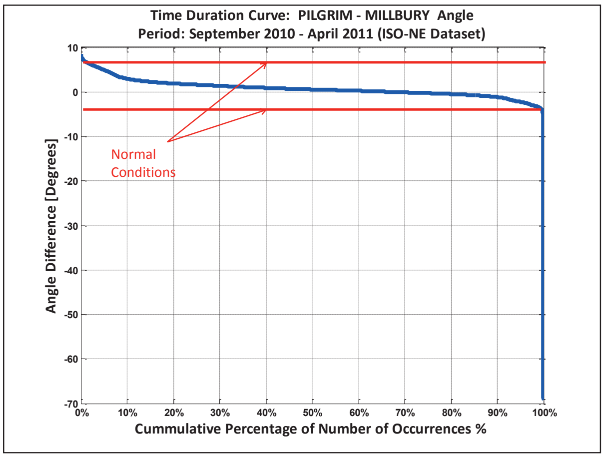

Box-Whisker Plot: CANAL - MILLBURY Daily Angle Difference
Period: May 2010 - July 2010
Voltage Angle Difference [Degrees]
Days
Threshold

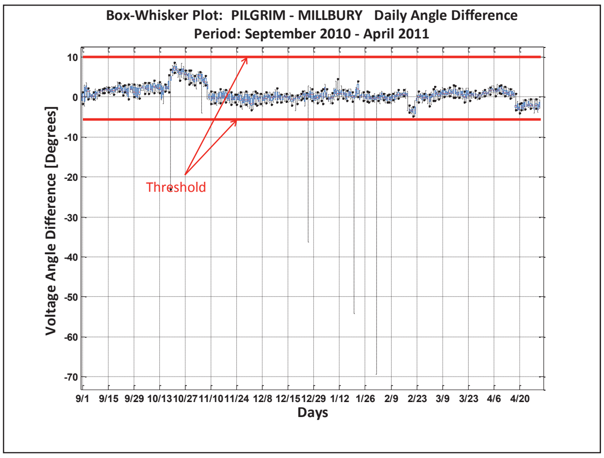

Time Duration Curve: CANAL - MILLBURY Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Angle Difference [Degrees]
Cummulative Percentage of Number of Occurrences %
Normal
Conditions

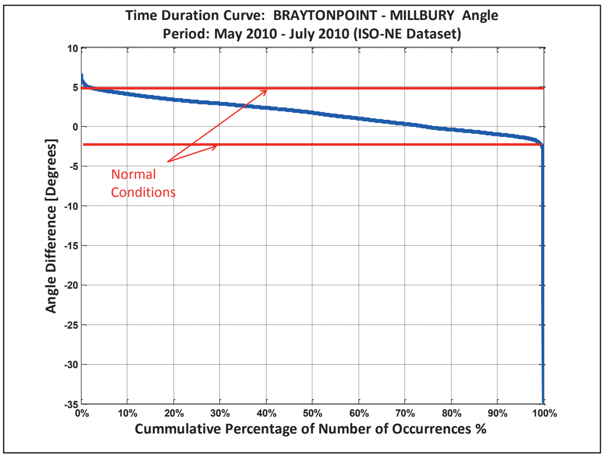

Box-Whisker Plot: CANAL - MILLBURY Daily Angle Difference
Period: September 2010 - April 2011
Voltage Angle Difference [Degrees]
Days
Threshold

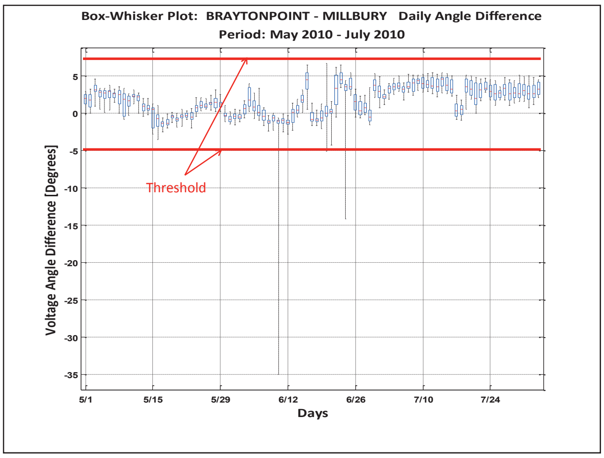

Time Duration Curve: PILGRIM - MILLBURY Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Normal
Conditions
Angle Difference [Degrees]
Cummulative Percentage of Number of Occurrences %

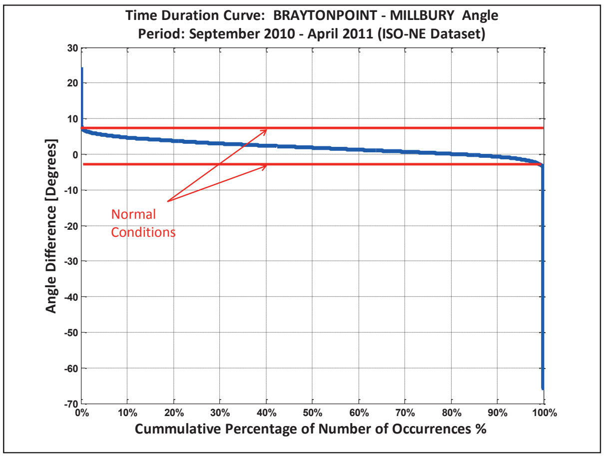

Box-Whisker Plot: PILGRIM - MILLBURY Daily Angle Difference
Period: May 2010 - July 2010
Threshold
Voltage Angle Difference [Degrees]
Days

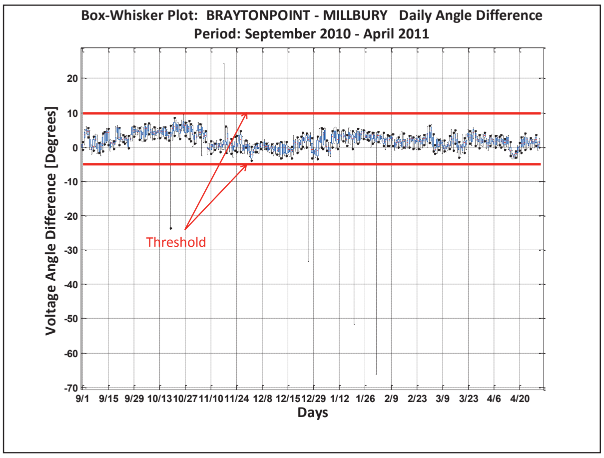

Time Duration Curve: PILGRIM - MILLBURY Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Normal
Conditions
Angle Difference [Degrees]
Cummulative Percentage of Number of Occurrences %


Box-Whisker Plot: PILGRIM - MILLBURY Daily Angle Difference
Period: September 2010 - April 2011
Threshold
Voltage Angle Difference [Degrees]
Days


Time Duration Curve: BRAYTONPOINT - MILLBURY Angle
Period: May 2010 - July 2010 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal Conditions
Cummulative Percentage of Number of Occurrences %


Box-Whisker Plot: BRAYTONPOINT - MILLBURY Daily Angle Difference
Period: May 2010 - July 2010
Voltage Angle Difference [Degrees]
Threshold
Days


Time Duration Curve: BRAYTONPOINT - MILLBURY Angle
Period: September 2010 - April 2011 (ISO-NE Dataset)
Angle Difference [Degrees]
Normal Conditions
Cummulative Percentage of Number of Occurrences %


Box-Whisker Plot: BRAYTONPOINT - MILLBURY Daily Angle Difference
Period: September 2010 - April 2011
Voltage Angle Difference [Degrees]
Threshold
Days

A.7 Examination of Correlation Between Angle Difference and MW Flows (Voltage Magnitude)

Examination of Correlation Between Angle Difference and MW Flows/Voltage

Monitored Bus Angle
Raun 345kV - Sub 91 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
SYCAMOR6 345.00-BONDRNT6 345.00-1	0.98	BONDRNT3 345.00-MNTZUMA3 345.00-1	0.90
BONDRNT6 345.00-MNTZUMA6 345.00-1	0.96	EAUCL3 345.00-ARP 345 345.00-1	0.88
BLUE LK6 345.00-PR ISLD6 345.00-1	0.94	ST LAKE 345.00-GARDNRPK 345.00-1	0.88
INVRHLS6 345.00-REDROCK6 345.00-1	0.92	ARP 345 345.00-ROCKY RN 345.00-1	0.88
BLUE LK6 345.00-INVRHLS6 345.00-1	0.90	ASKING3 345.00-EAUCL3 345.00-1	0.87
ARP 3453 345.00-ROCKY R3 345.00-1	0.88	QUAD ; 345.00-H471ESS 345.00-1	0.86
KOLMNLK6 345.00-AS KING6 345.00-1	0.88	CORDO; B 345.00-NELSO; B 345.00-1	0.86
HILLS 6 345.00-SUB 92 6 345.00-1	0.88	ROCKY RN 345.00-WERNER_W 345.00-1	0.85
SEPOLK 6 345.00-BONDRNT6 345.00-1	0.88	ARROWHD 345.00-ST LAKE 345.00-1	0.84
TERMINL6 345.00-KOLMNLK6 345.00-1	0.88	H471ESS 345.00-NELSO; B 345.00-1	0.84
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
EAU CL 6 345.00	-0.79	ARP 345 /**/345	-0.75
ARP 3453 345.00	-0.76	NELSO; B/**/345	-0.75
SPLT RK6 345.00	-0.72	EAUCL3 /**/345	-0.75
ROCKY R3 345.00	-0.69	H471ESS /**/345	-0.73
AS KING6 345.00	-0.67	CORDO; B/**/345	-0.68
155 NELS 345.00	-0.67	LEECO_EC/**/345	-0.68
H471 345.00	-0.65	CORDOME3/**/345	-0.67
937 LEE 345.00	-0.61	CORDO; /**/345	-0.67
MT VRNO3 345.00	-0.58	QUAD ; /**/345	-0.66
RAMSEY 3 345.00	-0.58	ROCKY RN/**/345	-0.66

Monitored Bus Angle
Goodings 345kV- Arcadian 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
22 ZION 345.00-ARCADIAN 345.00-1	0.88	ARCADN1 345.00-ZION ; B 345.00-1	0.90
ROCKDAL3 345.00-ROCKDAL3 138.00-1	0.70	LENNOX 460.00-LENNOX 19.000-T3	0.70
ROCKDAL3 345.00-ROCKDAL3 138.00-2	0.70	COL 345 345.00-ROE 345 345.00-1	0.64
ROCKDAL3 345.00-ROCKDAL3 138.00-3	0.70	NB159; R 345.00-SKOKIE01 345.00-1	0.63
101 ITAS 345.00-46 DESPL 345.00-1	0.67	DP 46; R 345.00-DP 46; B 345.00-DC	0.62
46 DESPL 345.00-172 GOLF 345.00-1	0.67	SKOKIE01 345.00-GOLFMILL 345.00-1	0.62
46 DESPL 345.00-46 DESPL 345.00-1	0.67	DP 46; B 345.00-ITASC; R 345.00-1	0.62
172 GOLF 345.00-88 SKOKI 345.00-1	0.66	GOLFMILL 345.00-DP 46; R 345.00-1	0.62
88 SKOKI 345.00-159 NORT 345.00-1	0.64	PLVLLY3 345.00-ADAMS 3 345.00-1	0.61
DUNWOODI 345.00-DUNWOODI 138.00-2	0.63	ADAMS 3 345.00-MITCHLCO 345.00-1	0.61
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
ROCKDAL3 345.00	-0.46	LUTESVIL/**/345	-0.44
LAKEFLD6 345.00	-0.44	7ESSEX /**/345	-0.42
WILMART6 345.00	-0.39	CRETE_EC/**/345	-0.40
PLAINS 3 345.00	-0.38	7NEWMAD /**/345	-0.40
MORGAN 3 345.00	-0.37	8COGNTRX/**/500	-0.40
COLMBIA3 345.00	-0.35	09STUART/**/345	-0.40
PALMYRA3 345.00	-0.35	JO 29; R/**/345	-0.40
PALM TA3 345.00	-0.34	17STJOHN/**/345	-0.39
NMA345-3 345.00	-0.34	CASEY /**/345	-0.39
DR NEU13 345.00	-0.34	34517_T /**/345	-0.39

Monitored Bus Angle
Goodings 345kV- Palisades 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
66 E FRN 345.00-970 UP N 345.00-1	0.91	UPNOR;RP 345.00-05OLIVE 345.00-1	0.91
970 UP N 345.00-OLIVE 345.00-1	0.91	EFRNKFRT 345.00-UPNOR;RP 345.00-1	0.91
STJOHNS 345.00-GREENACR 345.00-1	0.90	34517_T 345.00-17GRNACR 345.00-1	0.91
66 E FRN 345.00-945 CRET 345.00-1	0.88	17STJOHN 345.00-34517_T 345.00-1	0.91
945 CRET 345.00-STJOHNS 345.00-1	0.88	CRETE_EC 345.00-17STJOHN 345.00-1	0.89
BENTONHA 345.00-PALISAD2 345.00-1	0.87	EFRNKFRT 345.00-CRETE_EC 345.00-1	0.89
COOK 345.00-PALISAD2 345.00-1	0.86	BENTONHA 345.00-18PALISA 345.00-_1	0.88
COOK 345.00-BENTONHA 345.00-1	0.84	COOK 345.00-18PALISA 345.00-2	0.86
LEESBURG 345.00-HIPLE 345.00-1	0.84	05DUMONT 345.00-TWINBRAN 345.00-1	0.84
DUMONT2 345.00-TWINBRAN 345.00-1	0.84	05DUMONT 345.00-TWINBRAN 345.00-2	0.84
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
112 WILT 765.00	-0.82	BENTONHA/**/345	-0.80
23 COLLI 765.00	-0.81	COOK /**/345	-0.79
BENTONHA 345.00	-0.81	COLLINS1/**/765	-0.79
COOK 345.00	-0.78	WILTON00/**/765	-0.79
PALISAD2 345.00	-0.78	18PALISA/**/345	-0.77
COVERT 345.00	-0.78	05OLIVE /**/345	-0.77
OLIVE 345.00	-0.76	COVERT /**/345	-0.77
TWINBRAN 345.00	-0.75	05KENZIE/**/345	-0.76
KENZIECR 345.00	-0.74	COOK /**/765	-0.75
COOK 765.00	-0.74	TWINBRAN/**/345	-0.75

Monitored Bus Angle
Labadie 345kV - Hanna 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
BALDWIN3 345.00-PRAIRST 345.00-1	0.92	PRA28735 345.00-MT VRNON 345.00-DC	0.92
BALDWIN3 345.00-PRAIRST 345.00-2	0.92	ALBION 345.00-08GIBSON 345.00-1	0.89
PRAIRST 345.00-MT VRNO3 345.00-1	0.92	NORRIS 345.00-NORRIS 138.00-1	0.88
MT VRNO3 345.00-NEWTON 3 345.00-1	0.86	E W FKFT 345.00-NORRIS 345.00-1	0.88
NORRIS 3 345.00-NORRIS 3 138.00-1	0.86	CASEY 345.00-05BREED 345.00-1	0.84
E W FKF3 345.00-NORRIS 3 345.00-1	0.86	XENIA 345.00-NEWTON 345.00-1	0.84
CASEY 3 345.00-BREED 345.00-1	0.84	MT VRNON 345.00-XENIA 345.00-1	0.83
SIDNYCP3 345.00-BUNSONV3 345.00-1	0.83	BALDWIN 345.00-PRA28735 345.00-1	0.79
RUSH 3 345.00-BALDWIN3 345.00-1	0.82	BALDWIN 345.00-PRA28735 345.00-DC	0.79
CAMBEL 3 345.00-ROXFORD3 345.00-1	0.80	ROXFD IP 345.00-COFFEEN 345.00-1	0.77
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
NEOGA 3 345.00	-0.82	NEOGA /**/345	-0.86
HDNW 345.00	-0.82	MT VRNON/**/345	-0.82
RAMSEY 3 345.00	-0.76	XENIA /**/345	-0.81
CASEY 3 345.00	-0.73	RCCK /**/345	-0.81
MT VRNO3 345.00	-0.68	CASEY /**/345	-0.77
KANSAS 3 345.00	-0.65	RAMSEY /**/345	-0.75
937 LEE 345.00	-0.65	NORRIS /**/345	-0.70
BREED 345.00	-0.63	KANSAS /**/345	-0.68
SULLIVA2 345.00	-0.63	E W FKFT/**/345	-0.66
DARWIN 345.00	-0.63	E WFT IP/**/345	-0.66

CERTS NASPI Electric Power Group

Monitored Bus Angle
Labadie 345kV - Cumberland 500kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
FLETCH 345.00-ESSEXX 345.00-1	0.94	8SHAWNEE 345.00-8SHAWNEE 500.00-1	0.92
FLETCH 345.00-NEWMAD 345.00-1	0.94	7FLETCH 345.00-GOBKNOB 345.00-1	0.88
SHAWNEE4 345.00-SHAWNEE4 500.00-1	0.91	GOBKNOB 345.00-7WILHLM 345.00-1	0.87
PRAIRST 345.00-MT VRNO3 345.00-1	0.89	7SALEM 345.00-7FLETCH 345.00-1	0.86
NEWMAD 345.00-NEWMAD 500.00-2	0.88	8SHAWNEE 500.00-8MARSHAL 500.00-1	0.85
NEWMAD 345.00-NEWMAD 500.00-1	0.88	PRA28735 345.00-MT VRNON 345.00-DC	0.84
NEWMAD 500.00-DELL 500.00-1	0.88	7FRANKS 345.00-7SALEM 345.00-1	0.84
NEWMAD 345.00-DELL 500.00-1	0.86	ST FRANC 345.00-LUTESVIL 345.00-1	0.82
SALEMSPP 345.00-FLETCH 345.00-1	0.85	8MARSHAL 500.00-8CUMBERL 500.00-1	0.81
BALDWIN3 345.00-PRAIRST 345.00-1	0.84	ALBION 345.00-08GIBSON 345.00-1	0.73
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
112 WILT 765.00	-0.66	MT VRNON/**/345	-0.77
MT VRNO3 345.00	-0.65	LUTESVIL/**/345	-0.74
23 COLLI 765.00	-0.64	E WFT IP/**/345	-0.70
HDNW 345.00	-0.64	E W FKFT/**/345	-0.70
937 LEE 345.00	-0.63	NORRIS /**/345	-0.69
E W FKF3 345.00	-0.62	ST FRANC/**/345	-0.68
NORRIS 3 345.00	-0.61	KELSO /**/345	-0.68
RAMSEY 3 345.00	-0.61	RCCK /**/345	-0.66
SHAWNEE4 345.00	-0.61	XENIA /**/345	-0.66
155 NELS 345.00	-0.60	NEOGA /**/345	-0.62

CERTS NASPI Electric Power Group

Monitored Bus Angle
Jacksons Ferry 765kV- Cumberland 500kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
CORDOVA 500.00-JVILLE 500.00-1	0.80	8PHIPP B 500.00-05NAGEL 500.00-1	0.81
CASEY 3 345.00-BREED 345.00-1	0.75	CASEY 345.00-05BREED 345.00-1	0.74
PHIPPB 500.00-SULLIVA 500.00-1	0.72	8PHIPP B 500.00-8SULLIVA 500.00-1	0.74
WILSNTVA 500.00-ROANE 500.00-1	0.72	8WILSON 500.00-8ROANE 500.00-1	0.72
ROANE 500.00-BULLRU 500.00-1	0.68	8ROANE 500.00-8BULL RU 500.00-1	0.72
SIDNYCP3 345.00-BUNSONV3 345.00-1	0.67	05NAGEL 500.00-8SULLIVA 500.00-1	0.72
BFNP 500.00-MADISNTV 500.00-2	0.64	8JACKSON 500.00-8JVILLE 500.00-1	0.70
BFNP 500.00-MADISNTV 500.00-1	0.64	05BROADF 500.00-05BROADF 765.00-4	0.65
LOWNDES 500.00-MILLER 500.00-1	0.64	8SULLIVA 500.00-05BROADF 500.00-1	0.65
BROADFO2 500.00-BROADFO2 765.00-1	0.64	05BREED 345.00-SULLIVAN 100.00-1	0.63
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
GREENTO2 765.00	-0.67	05BREED /**/345	-0.65
SULLIVA2 345.00	-0.66	05SULLVA/**/765	-0.65
SULLIVA2 765.00	-0.66	COOK /**/345	-0.64
BREED 345.00	-0.66	05DARWIN/**/345	-0.63
DARWIN 345.00	-0.64	CASEY /**/345	-0.63
CASEY 3 345.00	-0.64	05OLIVE /**/345	-0.63
COOK 345.00	-0.63	05GRNTWN/**/765	-0.63
OLIVE 345.00	-0.63	05KENZIE/**/345	-0.63
NEOGA 3 345.00	-0.63	05JACKSR/**/345	-0.63
KENZIECR 345.00	-0.62	TWINBRAN/**/345	-0.62

CERTS NASPI Electric Power Group

Monitored Bus Angle
Canton Centr. 345kV - Monroe 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
BEAVER 345.00-CARLISLE 345.00-1	0.94	02BEAVER 345.00-02CARLIL 345.00-1	0.95
DAVISBES 345.00-BEAVER 345.00-1	0.90	02DAV-BE 345.00-02BEAVER 345.00-1	0.92
MIDWAYTE 345.00-LEMOYNE2 345.00-1	0.87	02MIDWAY 345.00-02LEMOYN 345.00-1	0.90
CARLISLE 345.00-N_MEDINA 345.00-1	0.87	05FOSTOR 345.00-05SBERWI 345.00-1	0.90
BAYSHOR2 345.00-DAVISBES 345.00-1	0.87	02BAY SH 345.00-02DAV-BE 345.00-1	0.89
MAJESTIC 345.00-LEMOYNE2 345.00-1	0.86	05SBERWI 345.00-02GALION 345.00-1	0.89
ALLENJUN 345.00-NSTARTAP 345.00-1	0.85	19MAJTC 345.00-02LEMOYN 345.00-1	0.89
LULU 345.00-ALLENJUN 345.00-1	0.83	02ALLEN 345.00-02NTAP 345.00-1	0.88
SBERWICK 345.00-GALION 345.00-1	0.82	02NTAP 345.00-02MIDWAY 345.00-1	0.88
BEAVER 345.00-AVONLAK2 345.00-2	0.81	02CARLIL 345.00-N_MEDINA 345.00-1	0.86
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
NIAGARA 345.00	-0.35	02DAV-BE/**/345	-0.38
BECK 345.00	-0.35	NANTICOK/**/460	-0.34
MCGUIRE4 500.00	-0.33	02BEAVER/**/345	-0.34
WOODLEAF 500.00	-0.32	W_LORAIN/**/345	-0.34
MARCY 765.00	-0.31	05CONES /**/345	-0.33
BEAVER 345.00	-0.30	MIDDLEPO/**/460	-0.31
ANTIOCH4 500.00	-0.29	AVON_FE /**/345	-0.30
PANNELL 345.00	-0.29	05NAGEL /**/500	-0.28
AVONLAK2 345.00	-0.28	8PHIPP B/**/500	-0.27
MARCY 345.00	-0.28	08ZIMER /**/345	-0.26

CERTS NASPI Electric Power Group

Monitored Bus Angle
Alburtis 500kV - Canton Centr. 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
KEYSTONE 500.00-JUNIATA 500.00-1	0.88	KEYSTNE1 500.00-JUNIATA 500.00-1	0.88
WYLIERID 500.00-CABOT 500.00-1	0.86	WYLIERID 500.00-CABOT 500.00-1	0.86
SUNBURY 500.00-SUSQUEHA 500.00-1	0.85	SUNBURY 500.00-SUSQUEHA 500.00-1	0.84
DOUBS 500.00-BRIGHTON 500.00-1	0.83	DOUBS 500.00-BRIGHTON 500.00-1	0.82
CONEMAUG 500.00-HUNTERST 500.00-1	0.82	JUNIATA 500.00-ALBURTIS 500.00-1	0.82
CONEMAUG 500.00-JUNIATA 500.00-1	0.81	CONEMAUG 500.00-HUNTERST 500.00-1	0.82
KEYSTONE 500.00-CONEMAUG 500.00-1	0.78	CONEMAUG 500.00-JUNIATA 500.00-1	0.81
ROCKSPRI 500.00-KEENEY 500.00-1	0.73	KEYSTNE1 500.00-CONEMAUG 500.00-1	0.78
PEACHBOT 500.00-ROCKSPRI 500.00-1	0.73	CONASTON 500.00-PEACHBOT 500.00-1	0.73
YUKON 500.00-SBEND 500.00-1	0.73	01RONCO 500.00-01HATFLD 500.00-1	0.72
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
CABOT 500.00	-0.76	JUNIATA /**/500	-0.90
KEYSTONE 500.00	-0.74	CABOT /**/500	-0.82
SBEND 500.00	-0.73	KEYSTNE1/**/500	-0.82
JUNIATA 500.00	-0.73	01SOBEND/**/500	-0.81
YUKON 500.00	-0.69	SUNBURY /**/500	-0.77
HOMERCIT 345.00	-0.67	WYLIERID/**/500	-0.76
CONEMAUG 500.00	-0.66	01YUKON /**/500	-0.71
SUNBURY 500.00	-0.65	TMI /**/500	-0.65
WYLIERID 500.00	-0.64	01WYLIER/**/345	-0.63
TMI 500.00	-0.60	CONEMAUG/**/500	-0.61

CERTS NASPI Electric Power Group

Monitored Bus Angle
Alburtis 500kV - Jacksons Ferry 765kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
DOUBS 500.00-BRIGHTON 500.00-1	0.90	DOUBS 500.00-BRIGHTON 500.00-1	0.90
KEYSTONE 500.00-JUNIATA 500.00-1	0.83	KEYSTNE1 500.00-JUNIATA 500.00-1	0.84
WYLIERID 500.00-CABOT 500.00-1	0.80	WYLIERID 500.00-CABOT 500.00-1	0.80
SUNBURY 500.00-SUSQUEHA 500.00-1	0.79	CONEMAUG 500.00-JUNIATA 500.00-1	0.79
CONEMAUG 500.00-JUNIATA 500.00-1	0.78	SUNBURY 500.00-SUSQUEHA 500.00-1	0.78
MTSTORM4 500.00-DOUBS 500.00-1	0.77	JUNIATA 500.00-ALBURTIS 500.00-1	0.77
CONEMAUG 500.00-HUNTERST 500.00-1	0.76	CONEMAUG 500.00-HUNTERST 500.00-1	0.77
HATFIELD 500.00-YUKON 500.00-1	0.75	MTSTO500 500.00-DOUBS 500.00-1	0.76
YUKON 500.00-SBEND 500.00-1	0.75	MTSTORM4 500.00-MTSTO500 500.00-DC	0.76
DOUBS 500.00-DOUBS 230.00-1	0.74	DOUBS 500.00-DOUBS 230.00-1	0.75
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
CABOT 500.00	-0.75	JUNIATA /**/500	-0.88
KEYSTONE 500.00	-0.73	SUNBURY /**/500	-0.80
YUKON 500.00	-0.73	CABOT /**/500	-0.79
JUNIATA 500.00	-0.73	WYLIERID/**/500	-0.77
SBEND 500.00	-0.73	KEYSTNE1/**/500	-0.77
SUNBURY 500.00	-0.71	01SOBEND/**/500	-0.76
HOMERCIT 345.00	-0.68	01YUKON /**/500	-0.72
CONEMAUG 500.00	-0.65	01WYLIER/**/345	-0.66
BELMONT 765.00	-0.63	TMI /**/500	-0.65
TMI 500.00	-0.63	05TIDD /**/345	-0.61

CERTS NASPI Electric Power Group

Monitored Bus Angle
Alburtis 500kV - Ramapo 500kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
BRANCHBU 500.00-RAMAPO 500.00-1	0.88		
RAMAPO 500.00-RAMAPO 345.00-1	0.88		
ELROY 500.00-BRANCHBU 500.00-1	0.81		
RAMAPO 345.00-RAMAPO 345.00-2	0.80		
ALBURTIS 500.00-BRANCHBU 500.00-1	0.79		
RAMAPO 345.00-RAMAPO 345.00-1	0.77		
ROCKTAVE 345.00-ROSETON 345.00-1	0.75		
SALEM 500.00-NEWFREED 500.00-1	0.72		
KEYSTONE 500.00-JUNIATA 500.00-1	0.68		
CONEMAUG 500.00-JUNIATA 500.00-1	0.68		
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
HOMERCIT 345.00	-0.60		
BRANCHBU 500.00	-0.57		
RAMAPO 345.00	-0.55		
WATERCUR 345.00	-0.54		
EWINDSOR 500.00	-0.50		
NHARBOR 345.00	-0.50		
KEYSTONE 500.00	-0.49		
SBEND 500.00	-0.49		
JUNIATA 500.00	-0.48		
GRANDISL 345.00	-0.48		

CERTS NASPI Electric Power Group

Monitored Bus Angle
Niagara 345kV- Monroe 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
PERRY_FE 345.00-ASHTABUL 345.00-1	0.78	LONGWOOD 460.00-NANTICOK 460.00-1	0.86
ASHTABUL 345.00-ERIEW 345.00-1	0.76	02PERRY 345.00-02S8-ATT 345.00-1	0.77
ERIES 345.00-ERIES 230.00-2	0.75	02S8-ATT 345.00-ERIE W 345.00-1	0.77
ERIEW 345.00-ERIES 345.00-1	0.75	ERIE W 345.00-ERIE SO 345.00-1	0.77
ERIES 345.00-ERIES 230.00-1	0.75	ERIE SO 345.00-ERIES 230.00-5	0.77
STEPHNS2 345.00-STCLAIR 345.00-1	0.71	ERIE SO 345.00-ERIES 230.00-8	0.77
JEWELL 345.00-STCLAIR 345.00-1	0.70	19BLRPP 345.00-19STCPP 345.00-1	0.71
DUNWOODI 345.00-PLVL NY 345.00-1	0.69	19STCPP 345.00-19STCPP 220.00-1	0.71
MILLWOOD 345.00-WOOD 345.00-1	0.69	19STEPH 345.00-19STCPP 345.00-1	0.71
WOOD 345.00-PLVY NY 345.00-1	0.69	19JEWEL 345.00-19STCPP 345.00-1	0.70
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
MILLSTON 345.00	-0.58	LEXINGTN/**/500	-0.57
PILGRIM 345.00	-0.58	05CLOVRD/**/500	-0.55
SANDYPON 345.00	-0.54	VALLEY4 /**/500	-0.53
CLOVERD2 500.00	-0.54	05CLOVRD/**/345	-0.52
CANAL 345.00	-0.53	05MFUNK /**/345	-0.49
STON NB 345.00	-0.53	LEXIN500/**/500	-0.48
HADDAMNE 345.00	-0.53	05J.FERR/**/765	-0.45
CLOVERD2 345.00	-0.51	05AXTON /**/765	-0.45
LEXINGTN 500.00	-0.51	BATHC500/**/500	-0.43
EDIC 345.00	-0.48	02MANSFD/**/345	-0.43

CERTS NASPI Electric Power Group

Monitored Bus Angle
Niagara 345kV- Ramapo 500kV

PJM Data		NYISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
KINTIGH 345.00-ROCHESTE 345.00-1	0.84		
MARCY 345.00-COOPERSC 345.00-1	0.81		
NIAGARA 345.00-ROCHESTE 345.00-1	0.80		
ROCHESTE 345.00-PANNELL 345.00-1	0.80		
ROCHESTE 345.00-PANNELL 345.00-2	0.80		
PANNELL 345.00-CLAY NY 345.00-1	0.79		
PANNELL 345.00-CLAY NY 345.00-2	0.79		
EDIC 345.00-FRASER 345.00-1	0.79		
FRASER 345.00-COOPERSC 345.00-1	0.79		
LAFA NY 345.00-OAKDALE 345.00-1	0.78		
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
ROCHESTE 345.00	-0.72	PANNELL_A006	-0.70
SOME NY 345.00	-0.72	CLAY_____345_____1	-0.68
GRANDISL 345.00	-0.67	ROCHESTR_345_____1	-0.67
YUKON 500.00	-0.63	WATRCURE_230_____1	-0.66
KIRK 345.00	-0.62	PLSNTVLY_345____15	-0.64
JUGSTRET 345.00	-0.62	GARDNVLA_230_____1	-0.63
WMILLERS 345.00	-0.62	RAMAPO___345____13	-0.62
CORRIDOR 345.00	-0.62	ROSETON__345_____1	-0.60
DUVAL 500.00	-0.62	LADENTWN_345_____6	-0.60
ROBERTS2 345.00	-0.61	COOPERS__345_____1	-0.59

Monitored Bus Angle
Ramapo 500kV – Millbury 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
WESTON 3 345.00-GARDNRPK 345.00-1	0.79	KEWAUNEE 345.00-KEWAUNEE 20.000-1	0.83
LONGMOUN 345.00-STON NB 345.00-1	0.78	LAKEFLD 345.00-LAKEFLD5 161.00-2	0.73
GARDNRPK 345.00-HIGHWY22 345.00-1	0.77	8ANO_50 500.00-ANO_U2 22.000-1	0.73
HIGHWY22 345.00-WERNER_W 345.00-1	0.76	SIBLEY 7 345.00-PHILL 7 345.00-1	0.72
ROCKY R3 345.00-WERNER_W 345.00-1	0.74	EFISH345 345.00-PLSNT345 345.00-1	0.71
HADDAMNE 345.00-STON NB 345.00-1	0.74	EFISH345 345.00-PLSNT345 345.00-2	0.71
FISHKILL 345.00-PLVY NY 345.00-1	0.72	NEWFREED 500.00-SALEM 500.00-1	0.70
FISHKILL 345.00-PLVY NY 345.00-2	0.72	19STEPH 345.00-19STCPP 345.00-1	0.70
STEPHNS2 345.00-STCLAIR 345.00-1	0.72	N_SCT345 345.00-ALPS 345 345.00-1	0.70
MILLSTON 345.00-STON NB 345.00-1	0.71	SAPULPA 345.00-R.S.S.-7 345.00-1	0.68
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
MILLSTON 345.00	-0.58	VALLE500/**/500	-0.61
PILGRIM 345.00	-0.54	N.E.S.-7/**/345	-0.54
SANDYPON 345.00	-0.54	ONETA--7/**/345	-0.51
EDIC 345.00	-0.52	CALPINE7/**/345	-0.51
HADDAMNE 345.00	-0.52	CONSTEL7/**/345	-0.51
STON NB 345.00	-0.51	R.S.S.-7/**/345	-0.50
CANAL 345.00	-0.48	TULSA_NO/**/345	-0.47
DR NEU13 345.00	-0.46	HOLLAND /**/345	-0.47
SALEM NE 345.00	-0.44	SAPULPA /**/345	-0.46
COMERFOR 345.00	-0.44	CLEVLND7/**/345	-0.46

Monitored Bus Angle
Raun 345kV- Ramapo 500kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
155 NELS 345.00-111 ELEC 345.00-1	0.77		
INVRHLS6 345.00-REDROCK6 345.00-1	0.77		
LEESBURG 345.00-HIPLE 345.00-1	0.75		
BLUE LK6 345.00-INVRHLS6 345.00-1	0.75		
SYCAMOR6 345.00-BONDRNT6 345.00-1	0.74		
AS KING6 345.00-EAU CL 6 345.00-1	0.74		
EAU CL 6 345.00-ARP 3453 345.00-1	0.73		
TERMINL6 345.00-KOLMNLK6 345.00-1	0.73		
KOLMNLK6 345.00-AS KING6 345.00-1	0.72		
HILLS 6 345.00-SUB 92 6 345.00-1	0.71		
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
COOK 765.00	-0.77		
DUMONT2 345.00	-0.77		
112 WILT 765.00	-0.77		
OLIVE 345.00	-0.77		
STILLWEL 345.00	-0.75		
TWINBRAN 345.00	-0.75		
23 COLLI 765.00	-0.74		
DUMONT2 765.00	-0.74		
KENZIECR 345.00	-0.73		
COOK 345.00	-0.72		

Monitored Bus Angle
Arcadian 345kV- Ramapo 500kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
TIDD_AEP 345.00-WYLIERID 345.00-1	0.73		
MALISZEW 765.00-KAMMER2 765.00-1	0.66		
HIPLE 345.00-COLLINGW 345.00-1	0.66		
RPMONE 345.00-ELIMA 345.00-1	0.66		
WYLIERID 500.00-CABOT 500.00-1	0.66		
BATTLECR 345.00-ONEIDA 345.00-1	0.64		
SUNBURY 500.00-SUSQUEHA 500.00-1	0.64		
ROBISONP 345.00-RPMONE 345.00-1	0.62		
KEYSTONE 500.00-JUNIATA 500.00-1	0.61		
CONASTON 500.00-PEACHBOT 500.00-1	0.61		
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
KAMMER2 500.00	-0.67		
KAMMER2 765.00	-0.65		
CABOT 500.00	-0.64		
WYLIERID 500.00	-0.62		
BELMONT 765.00	-0.60		
KEYSTONE 500.00	-0.60		
GREENTO2 765.00	-0.60		
SBEND 500.00	-0.60		
DUMONT2 345.00	-0.59		
LAKEGEOR 345.00	-0.59		

Monitored Bus Angle
Goodings 345kV- Monroe 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
LEESBURG 345.00-HIPLE 345.00-1	0.83	17LESBRG 345.00-17HIPLE 345.00-1	0.84
TWINBRAN 345.00-ARGENTA2 345.00-1	0.81	TWINBRAN 345.00-18ARGENT 345.00-1	0.82
COOK 345.00-BENTONHA 345.00-1	0.79	COOK 345.00-BENTONHA 345.00-1	0.79
COOK 345.00-PALISAD2 345.00-1	0.78	COOK 345.00-18PALISA 345.00-2	0.79
DUMONT2 345.00-TWINBRAN 345.00-1	0.77	05DUMONT 345.00-TWINBRAN 345.00-1	0.78
DUMONT2 345.00-TWINBRAN 345.00-2	0.77	05DUMONT 345.00-TWINBRAN 345.00-2	0.78
ELIMA 345.00-FOSTORIA 345.00-1	0.77	BENTONHA 345.00-18PALISA 345.00-_1	0.77
BENTONHA 345.00-PALISAD2 345.00-1	0.76	05ELIMA 345.00-05FOSTOR 345.00-1	0.77
PALISAD2 345.00-VERGENNE 345.00-1	0.74	05FOSTOR 345.00-02BAY SH 345.00-1	0.75
FOSTORIA 345.00-BAYSHOR2 345.00-1	0.73	18PALISA 345.00-18VERGEN 345.00-1	0.74
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
TWINBRAN 345.00	-0.85	BENTONHA/**/345	-0.87
BENTONHA 345.00	-0.85	18PALISA/**/345	-0.86
ARGENTA2 345.00	-0.84	TWINBRAN/**/345	-0.86
PALISAD2 345.00	-0.83	COVERT /**/345	-0.86
COVERT 345.00	-0.83	18ARGENT/**/345	-0.85
KENZIECR 345.00	-0.83	05KENZIE/**/345	-0.85
OLIVE 345.00	-0.82	COOK /**/345	-0.84
DUMONT2 345.00	-0.81	05OLIVE /**/345	-0.83
JACKSONR 345.00	-0.81	05JACKSR/**/345	-0.83
COOK 345.00	-0.81	G ACR; T/**/345	-0.81

CERTS NASPI Electric Power Group

Monitored Bus Angle
Goodings 345kV- Hanna 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
116 GOOD 345.00-11613 345.00-1	0.83	05DUMONT 345.00-05SORENS 345.00-1	0.82
STJOHNS 345.00-GREENACR 345.00-1	0.79	GOODI;2R 345.00-11613LIN 345.00-1	0.81
970 UP N 345.00-OLIVE 345.00-1	0.77	17STJOHN 345.00-34517_T 345.00-1	0.80
66 E FRN 345.00-970 UP N 345.00-1	0.77	34517_T 345.00-17GRNACR 345.00-1	0.80
DUMONT2 345.00-SORENSON 345.00-1	0.77	UPNOR;RP 345.00-05OLIVE 345.00-1	0.77
23 COLLI 345.00-23 COLLI 1.0000-1	0.76	RISING 345.00-RISING 138.00-1	0.77
GREENACR 345.00-OLIVE 345.00-1	0.76	GOS_CK_W 345.00-RISING 345.00-1	0.77
STILLWEL 345.00-DUMONT2 345.00-1	0.75	EFRNKFRT 345.00-UPNOR;RP 345.00-1	0.77
BABCOCK 345.00-STILLWEL 345.00-1	0.75	COLLINS1 345.00-COLLINS1 1.0000-1	0.76
WALTON_3 345.00-WALTON_3 230.00-1	0.74	G ACR; T 345.00-05OLIVE 345.00-1	0.76
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
112 WILT 765.00	-0.63	COLLINS1/**/765	-0.63
23 COLLI 765.00	-0.62	WILTON00/**/765	-0.62
DUMONT2 765.00	-0.50	PLANO; /**/765	-0.55
COOK 765.00	-0.47	NEOSHO 7/**/345	-0.54
STILLWEL 345.00	-0.42	05DUMONT/**/765	-0.50
COOPER 6 345.00	-0.41	COOK /**/765	-0.49
DUMONT2 345.00	-0.40	HITCH /**/345	-0.48
S3451 6 345.00	-0.40	POTTRC7 /**/345	-0.48
GREENACR 345.00	-0.40	GRTPLAIN/**/345	-0.47
COLESONC 345.00	-0.39	ST FRANC/**/345	-0.47

CERTS NASPI Electric Power Group

Monitored Bus Angle
Hanna 345kV- Monroe 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
ELIMA 345.00-FOSTORIA 345.00-1	0.97	05ELIMA 345.00-05FOSTOR 345.00-1	0.97
FOSTORIA 345.00-LEMOYNE2 345.00-1	0.93	05FOSTOR 345.00-02LEMOYN 345.00-1	0.93
FOSTORIA 345.00-BAYSHOR2 345.00-1	0.90	05FOSTOR 345.00-02BAY SH 345.00-1	0.91
SORENSON 345.00-ALLENIM 345.00-1	0.86	05SORENS 345.00-05ALLEN 345.00-1	0.88
SWLIMA 345.00-ELIMA 345.00-1	0.85	05ALLEN 345.00-05ROBPK 345.00-1	0.87
ALLENIM 345.00-ROBISONP 345.00-1	0.84	05SWLIM 345.00-05ELIMA 345.00-1	0.85
SUNNYSID 345.00-FALLCREE 345.00-1	0.82	16SUNNYS 345.00-05FALLC 345.00-1	0.84
BAYSHOR2 345.00-MONROE 345.00-1	0.79	05FALLC 345.00-05DESOTO 345.00-1	0.80
FALLCREE 345.00-DESOTO 345.00-1	0.78	02BAY SH 345.00-19MON12 345.00-1	0.79
DESOTO 345.00-KEYSTNE 345.00-1	0.76	02GALION 345.00-05SBERWI 345.00-1	0.77
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
VERGENNE 345.00	-0.78	18GAINES/**/345	-0.76
GAINES 345.00	-0.77	18ARGENT/**/345	-0.76
ARGENTA2 345.00	-0.77	18VERGEN/**/345	-0.76
PALISAD2 345.00	-0.72	18PALISA/**/345	-0.74
COVERT 345.00	-0.72	COVERT /**/345	-0.74
NELSONRD 345.00	-0.72	BENTONHA/**/345	-0.72
RENAISSA 345.00	-0.72	18BATTLE/**/345	-0.72
BATTLECR 345.00	-0.72	TWINBRAN/**/345	-0.65
BENTONHA 345.00	-0.70	05KENZIE/**/345	-0.64
KENOWA 345.00	-0.66	18KENOWA/**/345	-0.63

CERTS NASPI Electric Power Group

Monitored Bus Angle
Hanna 345kV- Canton Centr. 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
MALISZEW 765.00-KAMMER2 765.00-1	0.83	MALISZEW 765.00-05KAMMER 765.00-1	0.85
TIDD_AEP 345.00-WYLIERID 345.00-1	0.76	05MARYSV 765.00-MALISZEW 765.00-1	0.84
ELIMA 345.00-FOSTORIA 345.00-1	0.76	05SECANT 345.00-05CANTNC 345.00-1	0.77
SORENSON 345.00-ALLENIM 345.00-1	0.74	05TIDD 345.00-01WYLIER 345.00-1	0.76
LEMOYNE2 345.00-DAVISBES 345.00-1	0.74	05ELIMA 345.00-05FOSTOR 345.00-1	0.75
BEVERLY2 345.00-TIDD_AEP 345.00-1	0.72	02LEMOYN 345.00-02DAV-BE 345.00-1	0.74
CANTONCE 345.00-HANNAOE 345.00-1	0.72	05SORENS 345.00-05ALLEN 345.00-1	0.73
FALLCREE 345.00-DESOTO 345.00-1	0.69	05CANTNC 345.00-02HANNA 345.00-1	0.72
ALLENIM 345.00-ROBISONP 345.00-1	0.68	05BEVERL 345.00-05TIDD 345.00-1	0.71
NLONGVW 500.00-FTMARTIN 500.00-1	0.68	05ROBPK 345.00-05CONVOY 345.00-1	0.71
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
KAMMER2 765.00	-0.76	KAMMER /**/500	-0.73
KAMMER2 500.00	-0.76	05KAMMER/**/765	-0.72
SCANTON2 765.00	-0.68	05SCANTO/**/765	-0.68
SPORNAEP 345.00	-0.67	MARQUIS /**/345	-0.68
BELMONT 765.00	-0.67	06DOE530/**/345	-0.67
RPMONE 345.00	-0.64	05BELMON/**/765	-0.66
GREENTO2 765.00	-0.63	05WBELLA/**/345	-0.66
DOEX530 345.00	-0.62	05CONVOY/**/345	-0.65
KYGERCRE 345.00	-0.62	05GRNTWN/**/765	-0.64
BATTLECR 345.00	-0.61	05MERIDN/**/345	-0.64

CERTS NASPI Electric Power Group

Monitored Bus Angle
Palisades 345kV- Monroe 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
ELIMA 345.00-FOSTORIA 345.00-1	0.83	05ELIMA 345.00-05FOSTOR 345.00-1	0.85
ONEIDA 345.00-MAJESTIC 345.00-1	0.82	18BATTLE 345.00-18ONEIDA 345.00-1	0.84
BATTLECR 345.00-ONEIDA 345.00-1	0.82	18ONEIDA 345.00-19MAJTC 345.00-1	0.84
ARGENTA2 345.00-BATTLECR 345.00-1	0.75	18ARGENT 345.00-18BATTLE 345.00-1	0.74
VERGENNE 345.00-NELSONRD 345.00-1	0.73	18GOSS 345.00-18THETFR 345.00-1	0.73
CANTONCE 345.00-HANNAOE 345.00-1	0.71	05FOSTOR 345.00-02BAY SH 345.00-1	0.73
FOSTORIA 345.00-BAYSHOR2 345.00-1	0.70	05CANTNC 345.00-02HANNA 345.00-1	0.73
NELSONRD 345.00-GOSS 345.00-1	0.70	18NELRD 345.00-18GOSS 345.00-1	0.72
MAJESTIC 345.00-COVENTRY 345.00-1	0.70	02STAR 345.00-02JUNIPE 345.00-1	0.71
STAR_FE 345.00-JUNIPER 345.00-1	0.69	05FOSTOR 345.00-02LEMOYN 345.00-1	0.71
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
NELSONRD 345.00	-0.74	05ELIMA /**/345	-0.68
RENAISSA 345.00	-0.74	18BATTLE/**/345	-0.68
ELIMA 345.00	-0.67	18ONEIDA/**/345	-0.67
BATTLECR 345.00	-0.67	MARQUIS /**/345	-0.66
RPMONE 345.00	-0.66	06DOE530/**/345	-0.66
VERGENNE 345.00	-0.65	05CONVOY/**/345	-0.66
GAINES 345.00	-0.65	18GAINES/**/345	-0.64
KYGERCRE 345.00	-0.64	18VERGEN/**/345	-0.63
ARGENTA2 345.00	-0.63	18ARGENT/**/345	-0.62
DOEX530 345.00	-0.63	05MERIDN/**/345	-0.62

Monitored Bus Angle
Raun 345kV - Millbury 345kV

PJM Data		MISO Data	
Top 10 Transmission Lines Ranked by Correlation Coefficient between Monitored Bus Angle and MW Flow			
155 NELS 345.00-111 ELEC 345.00-1	0.80	NELSO; B 345.00-ELECT; B 345.00-1	0.75
ROCKY R3 345.00-WERNER_W 345.00-1	0.78	HILLS 3 345.00-SUB 92 3 345.00-1	0.66
BLUE LK6 345.00-INVRHLS6 345.00-1	0.75	BONDRNT3 345.00-MNTZUMA3 345.00-1	0.65
GARDNRPK 345.00-HIGHWY22 345.00-1	0.75	HILLS 3 345.00-SUB T 3 345.00-1	0.65
INVRHLS6 345.00-REDROCK6 345.00-1	0.75	17LESBRG 345.00-17HIPLE 345.00-1	0.64
AS KING6 345.00-EAU CL 6 345.00-1	0.73	MNTZUMA3 345.00-HILLS 3 345.00-1	0.63
HIGHWY22 345.00-WERNER_W 345.00-1	0.72	OVERTON 345.00-MCRD 345.00-1	0.63
SYCAMOR6 345.00-BONDRNT6 345.00-1	0.72	7SALEM 345.00-7FLETCH 345.00-1	0.62
WERNER_W 345.00-N APP 23 345.00-1	0.71	KEWAUNEE 345.00-KEWAUNEE 20.000-1	0.62
HIGHWY22 345.00-MORGAN 3 345.00-1	0.71	7FAIRPT 345.00-ST JOE 3 345.00-1	0.61
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
COOK 765.00	-0.72	WILTON00/**/345	-0.71
112 WILT 765.00	-0.71	VALLE500/**/500	-0.70
DUMONT2 765.00	-0.70	COOK /**/765	-0.67
DUMONT2 345.00	-0.69	WILTON00/**/765	-0.66
OLIVE 345.00	-0.68	05DUMONT/**/345	-0.64
167 PLAN 765.00	-0.67	05DUMONT/**/765	-0.64
TWINBRAN 345.00	-0.67	05OLIVE /**/345	-0.64
23 COLLI 765.00	-0.67	COLLINS1/**/765	-0.63
COOK 345.00	-0.67	TWINBRAN/**/345	-0.62
KENZIECR 345.00	-0.66	05KENZIE/**/345	-0.61

Monitored Bus Angle
Arcadian 345kV - Millbury 345kV

PJM Data		MISO Data	
HOMERCIT 345.00-WATERCUR 345.00-1	0.68	MALISZEW 765.00-05KAMMER 765.00-1	0.59
MALISZEW 765.00-KAMMER2 765.00-1	0.62	05MARYSV 765.00-MALISZEW 765.00-1	0.58
KEYSTONE 500.00-CONEMAUG 500.00-1	0.61	KEYSTNE1 500.00-CONEMAUG 500.00-1	0.58
HIPLE 345.00-COLLINGW 345.00-1	0.61	8B.WLSN 500.00-B_WLSN 1.0000-1	0.58
116 GOOD 345.00-66 E FRN 345.00-1	0.60	17HIPLE 345.00-05COLNGW 345.00-1	0.57
KYGERCRE 345.00-SPORNAEP 345.00-1	0.58	HOMER CY 345.00-WATRC345 345.00-1	0.57
DUMONT2 765.00-MARYSVI2 765.00-1	0.57	KEWAUNEE 345.00-KEWAUNEE 20.000-1	0.57
TWINBRAN 345.00-ARGENTA2 345.00-1	0.56	GOODI;2R 345.00-EFRNKFRT 345.00-1	0.55
WMILLERS 345.00-MUSKING2 345.00-1	0.56	06KYGER 345.00-SPORN 345.00-1	0.55
TIDD_AEP 345.00-WYLIERID 345.00-1	0.56	05OLIVE 345.00-05DUMONT 345.00-2	0.54
Top 10 Buses Ranked by Correlation Coefficient between Monitored Bus Angle and Bus Voltage			
DUMONT2 765.00	-0.59	VALLE500/**/500	-0.66
COOK 765.00	-0.57	WILTON00/**/345	-0.56
DUMONT2 345.00	-0.56	COOK /**/765	-0.54
TWINBRAN 345.00	-0.56	05DUMONT/**/765	-0.54
ARGENTA2 345.00	-0.55	TWINBRAN/**/345	-0.52
KENZIECR 345.00	-0.54	05DUMONT/**/345	-0.52
STILLWEL 345.00	-0.52	05KENZIE/**/345	-0.50
BENTONHA 345.00	-0.52	18ARGENT/**/345	-0.49
112 WILT 765.00	-0.51	05JACKSR/**/345	-0.49
JACKSONR 345.00	-0.51	17STLWEL/**/345	-0.48